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THE HEARING OF PRIMITIVE PEOPLES

AN EXPERIMENTAL STUDY OF THE AUDITORY ACUITY AND THE UPPER LIMIT OF HEARING OF WHITES, INDIANS, FILIPINOS, AINU AND AFRICAN PIGMIES

BY

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Submitted in partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy, in the Faculty of Philosophy, Columbia University.

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INTRODUCTION

In the pages which follow are presented some data relating to the problem of the hearing of primitive peoples. The study was made in connection with other experiments on the inferior races at the Louisiana Purchase Exposition in 1904. During the period of the Exposition, the writer, in the capacity of Assistant Superintendent of the Sections of Anthropometry and Psychometry, under the Division of Anthropology, in cooperation with Dr. (now Professor) R. S. Woodworth, who was his immediately superior officer, was commissioned to make a study, so far as practicable, of the mental and physical status of the alien races stationed on the Exposition grounds. In the arrangements for the tests, the entire problem of the hearing of these people was assigned to me—the ways and means of testing their hearing, together with the turn and scope the particular study of hearing should take.

When it came to the question of selecting the tests to be made, there was little of historical precedent to aid in making a choice. Dr. Charles Myers, in the only extended report on the hearing of primitive peoples extant, had examined three phases of hearing, namely: (1) The upper threshold of pitch, (2) the acuity for tones of medium pitch, and (3) the perception of interval. In addition to these three tests, a number of others, which might have brought out interesting and instructive results, suggested themselves to me. These related to space perception, tone memory and imagery, and clang preferences. The scope of our work, however, was subject to certain definite limitations.

In all, there were stationed at the Exposition in one capacity or another, something like one thousand individuals of various races, whom it might be possible to measure. There were two of us to carry on the work. One of two alternatives, consequently, must be pursued, (*a*) to restrict the number of measurements which should be made of each individual or (*b*) to confine the measurements to a few representative individuals and races. We chose the first in the hope that with relatively large groups some fairly definite information could be obtained. In consequence of this limitation of the number of measurements, it was thought advisable to confine the number of tests of hearing to three or four. After some considera-

tion and advisement, I selected the three[1] which Dr. Myers had made on the Papuans.

So far as practicable in these tests of primtive peoples, I hoped to be able to present my conclusions in such terms that the data might, if desired at some subsequent time, be reviewed and the measurements compared. I have consequently attempted to express my data in definitely interchangeable units, that is in acoustical units which are wholly objective in character. Much of the work included in this report, for this reason, is wholly a matter of physics. It concerns itself with the graduation of the instruments employed, but, for purposes of a quantitative psychology, this phase of the problem is none the less important.

In this connection, I desire to express my indebtedness of one kind or another, to those who have particularly assisted me in the undertaking and completion of the study herein reported. To Professor Cattell, first of all, I am especially indebted for suggestions relating to the problem as my particular field of research and for many valuable and kindly hints and criticisms in the treatment of

[1] The instruments and methods with reference to the first two named, (1) the measure of the upper threshold for hearing and (2) the determination of the acuity for tones lying within the range of conversational speech, will be fully detailed in the proper place. With reference to the perception of interval, however, a word is necessary in this connection.

The usual method of testing the perception of a musical interval is with the aid of tuning forks. I took to the Exposition two König tuning forks, differing from each other by four full vibrations, the one having a vibration frequency of 512, the other 516. On one of the prongs of the fork of lower pitch I placed a metallic rider, which it was possible to slide up and down and which might be fixed readily by means of an ordinary thumb screw. Thus the pitch of the fork could be raised or lowered without occasioning any wearisome delays. It seemed impossible, however, to arrange the rider in such a way as not to alter the character of the tone which followed independently of its purely pitch character. With the rider attached, the two forks possessed marked characteristics of clang tint by which they could be distinguished, wholly independently of the feeling of a pitch difference. My subjects were repeatedly warned that they should neglect the individual peculiarities in the two tones and render a judgment based only on their recognition of a difference of pitch. It appeared that this even my most intelligent subjects were unable to do, for questionings always showed that the individual peculiarity of the tone of each fork had become fixed during the earlier moments of the test, when the difference in pitch would be so marked as to be easily observed by all the subjects. Such a method of conducting the experiment as that just indicated seems necessary with children and intelligent adults to impress the object of the test.

Since, with intelligent white subjects, it seemed impossible to secure satisfactory data, it appeared unreasonable to presume that anything could be gained from this test on the primitive peoples. This test, therefore, was abandoned altogether and the hearing tests confined to two, (1) simple acuity and (2) upper threshold of hearing.

the results. To Professor Woodworth, it is impossible to express the full extent of my obligations. He performed large numbers of the tests. He, chiefly, was instrumental in making the arrangements with the officials in charge of the several groups for having the natives brought to our laboratories for testing. His searching criticisms, encouragement and interest at all times during the months at the Exposition, and subsequently, in the work of graduating the instruments have been an unfailing source of inspiration. To Professor W J McGee, Chief of the Department of Anthropology at the Louisiana Purchase Exposition, I am indebted directly for my selection to carry on the work. His encouragement in the work also and his assistance and cooperation in having the peoples brought to the laboratories for measurement was of inestimable worth. To S. M. McCowan, Superintendent of the Chilocco Indian School, who had charge of the Indian Ethnological exhibit at the Exposition, I am indebted for the privilege of measuring the Indians of the School, and to Major William Haskell, U. S. A., for the privilege of measuring the Philippine Constabulary soldiery. For assistance in interpreting directions and otherwise aiding the measurements, I was under obligations to Mr. Inagaki, of Tokio, in connection with the Ainu, Reverend S. V. Verner, in connection with the Pigmies, Dr. William Newcomb, in connection with the Vancouver Indians, and to Mr. Cushman, in connection with the Cocopas. Finally, and in a more comprehensive sense, I am indebted to all those who offered themselves as subjects for measurements, the mention of whose names alone would require many pages. Though mentioned in this general way only, my feeling of thankfulness to them is no less sincere.

CHAPTER I

The Peoples

In all, I was able to secure hearing records, which were more or less suitable for use in making various deductions indicating individual and racial differences, from about four hundred individuals. These were distributed as follows: 156 Whites; 63 Indians; 137 Filipinos (Christianized); 10 Cocopa Indians; 7 Ainu from the Island of Hokkaido, Japan; 7 Indians from Vancouver's Island; 6 so-called African Pigmies; and 4 Indians from the region of Southern Patagonia.

The Whites.—The Whites whom we measured were those, for the most part, who strolled through our laboratories primarily to view the exhibits, but offered themselves as subjects for our tests, willing victims to be sacrificed, as we chose, in the interest of the furtherance of scientific truth. We examined altogether about 100 of each sex but many of the records were unavailable for my purposes, either because the subjects were too young to be used in comparative tests or, to be sure, because they had advanced too far in years to make data concerning their hearing of value in comparison with those of younger individuals of other races. Many of the individuals were graduates from colleges and universities, others were school teachers. A number of professional and business men and women helped make up the number. Indeed, for the most part the group was made up of intelligent people.

The Indians.—Except the Christianized Filipinos and Whites, the Indians constituted the most numerous group tested. However, it can not be said that the Indians measured formed a single group, for they were brought from regions as widely separated as the Vancouver Islands and Patagonia. They belonged to approximately fourteen different stocks, as may be seen by the groupings below.

The greatest number of individuals belonged to the Algonkian stock. Next in order came the Shoshones, then the Sioux, Pima, Iroquoian in the order given.

During the whole of the Exposition period there were kept at the Indian School for purposes of exhibition something like 77 Indians. Of this number we tested 27 males and 44 females. Of the males, 14 were full-blooded and 13 mixed-bloods. Among the females, but four were of true stock. The mixed-bloods were in all cases partly

Stock or Family	Tribe	Stock or Family	Tribe
Algonkian	Sac and Fox	Piman	Pima
	Shawnee		Opata
	Pottawattomie		Papago
	Piegan		
	Chippeway	Iroquoian	Oneida
	Kickapoo		Cherokee
	Cheyenne		
		Scattered Tribes	Navajo
Shoshones	Comanche	belonging to as	Pawnee
	Chemehuevi	many stocks	Silitz
	Hopi or Moki		Muskoki
			Payallup
Siouan	Sioux		Kwaguitl
	Ponca		Cocopa or Seri
	Otae		Tehuelche

white—that is, partially American, Scotch, French, German, Swedish, Spanish or Irish. Not a single individual among the Indian group, so far as we know, possessed a negro strain in his inheritance.

It may well be questioned whether any group of individuals so heterogeneously conditioned as was this, might, with propriety, be lumped and treated as if representative or typical of the race. Indeed, were we dealing with traits in which tribal and stock differences are marked, as for example, anatomical features, such a procedure would be wholly unwarranted. Sensory features, however, are subject to a smaller range of variation. Moreover, these Indians from the Model Indian School came largely from the Indian schools at Haskell, Chilocco, Genoa, Phœnix and Ft. Shaw. Many of the boys and girls were taken from their homes at an early age and boarded at the Indian schools where they were subjected to social habits, intellectual training and industrial occupations which are common to whites. For the most part, they conducted themselves as do the young men and women of our cities. So far as their attitude toward society is concerned, one could not detect anything that would point directly to their immediately native origin. Hearing tests, moreover, look to constitutional differences rather than anything that may be directly influenced by a social veneer, hence the culture to which these boys and girls had been subjected, we might with reason aver, would affect their sensory reactions only very remotely.

The membership of the Model Indian School was made up of individuals belonging to the first twenty-two tribes named above, excluding the Hopi or Moki people who were connected with a concession on the Pike. Obviously, the numbers are altogether too few

to bring out tribal differences. All considered, therefore, it seems best to treat the membership of the Indian School as a single cultural group, nor does it seem necessary to indicate with reference to this group such physical and mental traits as mark off the various tribes of Indians aligned under the several stocks or families. Having lived for three or four years directly under the influence and training of an American civilization, the factors which might arise from differences in home life and ancestry are for the most part obliterated.

The Filipinos.—The 137 Filipinos whose hearing was tested all belonged to that branch of the Philippine soldiery known as the Constabulary. They constitute the local police of the Islands, being stationed in squads of eight in the different villages and districts, to preserve order. Inasmuch as the Constabulary is a branch of the local civil service and the remuneration is considerably in excess of that received for other manual vocations, the better element of the citizenship has been attracted to its ranks. Those brought to St. Louis were men in the prime of life, none older than thirty-five years or younger than seventeen. All had attended school to a certain extent at least. None was found to be illiterate or unable to write his name, tribe, and place of residence in the Islands. Many of the men were sons in well-to-do families who had attended the Spanish and parochial high schools and colleges found in the Philippines. Rather indicative of the scholarly habits of many of the younger men was their activity in acquiring our language. It was not uncommon to observe groups of men collected in some place apart with dictionary and grammar, assiduously studying English grammatical forms and usages.

In collecting the group for representation at the Exposition, it appears that the men were drafted in squads of eight from the various Constabulary regiments located in every part of the Archipelago, there being, in fact, eight from the Moro population of the Island of Mindanao. The tribes represented were the Tagalog, Visayan, Ilocano, Bicol, Macabebe, Pampanga, Pangasinan and other less well established tribes. It does not appear that any criteria of stature, strength and intelligence were used in selecting the individuals for representation. Two legs, two arms and two eyes were required. Besides, it was necessary for the recruit to understand enough Spanish to take the orders of the line in that tongue. Other than these, there seem to have been no prerequisites.

The Cocopa or Seri Indians.—The Cocopa or Seri Indians tested were all males. For one reason or another, sickness, timidity, indolence, the women of the tribe could not be induced to come to the

laboratories where the measuring was being done. It was chiefly through the instrumentality of Professor W J McGee that the Seri Indians were brought to the Exposition.[1] As the result of a careful and painstaking study of the social habits, customs and physical characteristics of this interesting group of people, Dr. McGee speaks in the following words: "Isolated to a considerable extent on Tiburon Island (in northwest Mexico) these people have successfully resisted the innovations of the white man. To-day they still cultivate aboriginal crops by aboriginal methods. They are said to be of so low a grade of culture that they may be classed as just entering the stone age. Physically, the Seri are a gigantic people, perhaps not excelled in their physical proportions by any other known tribe. Force of circumstances has made them an agricultural people chiefly, though the Cocopa are also given to the chase." Their habitations are extremely crude and primitive. Coarse grass, branches, leaves or whatever may be most convenient are thrown upon a crude framework of poles for a roof, while the same sort of an improvised material serves for walls. Such a habitation serves illy the purposes of protection from either heat or storm. The Seri Indians are not as intelligent as the average of the Indian race. They are inert, unresponsive to new impressions, dull and stupid in the face of an untried problem, and succumb readily to a difficult situation. With the older members of the group, especially, our efforts to make them approach our tests intelligently had been almost baffling were it not for the very able assistance and encouragement of an intelligent native interpreter, a half-blood woman who very ably interpreted our directions to the several subjects, but even with this, in some cases, the task seemed hopeless. Auditory acuity measures, however, being extremely simple, less difficulty was experienced with respect to them.

The Ainu.—The Ainu, four males and three females of whom we tested, are a people of more than ordinary ethnological interest. Surrounded by peoples of yellow skin, scant beard and little body hair with a head covering of straight black hair, the Ainu are white (when free from dirt) and their bodies and faces so profusely grown with a thick coat of hair that they have been popularly described as the hairy Ainu. The hair, too, is brown and wavy rather than straight. They inhabit the Island of Hokkaido or Yezo of the Japanese group. Little is known of the people's origin or ethnic relations. Until recently they had been little disturbed by other peoples, even by the Japanese among whom they dwell. While

[1] Professor McGee made some extensive explorations in the Seri country, which are reported at length in the Annual Report of the Smithsonian Institution for the year 1895–96 (Part I., pp. 1–295).

natively the Ainu are hunters and farmers, those at the Exposition had been under the influence of American missionaries, chief of whom is the famous Mr. Bachelor whose influence with the native Ainu has been remarkable. Through his influence it was that the people consented to leave their native land for the journey to this far off country. One of the Ainu young men had attended Mr. Bachelor's mission school, another had been a servant to another missionary. The father of the household, an old patriarch, had also been converted to the Christian faith, but had never quite surrendered all of his native instincts and superstitions. He was a farmer and bear hunter and still clung to the superstitions attaching to the erection of a bear head at the door of the dwelling to ward off evil spirits and omens.

The Ainu are short and stocky, sluggish in movement, deliberate in action, excessively timid in the face of a novel situation, and, taken all in all, very immature in their mental conceptions and aptitudes. However, they were willing and patient in the tests to a degree to cast reproach upon many of our white subjects. The Ainu were brought to America by Professor Frederick Starr of the University of Chicago. We were much indebted also to Mr. Y. Inagaki, a Japanese student, familiar with the Ainu language, who interpreted our directions to the Ainu subjects. In fact, in many ways, Mr. Inagaki's kindly interest and assistance alone made the tests on these people at all possible. Especially was this true because of their excessive timidity.

Vancouver Indians.—The Vancouver Indians belonged to two tribes, the Kwaguitl and the Nutken. There were present at the Exposition, two members of the first named tribe and five of the latter. Like the Ainu just described, some of these people were interrelated. At least four of the group of seven tested were closely so, though we were unable to discover in all cases the exact character and extent of the consanguinity. There were Atleo, an old man of perhaps 65 years, his two daughters, Ellen, aged 35, and Anna, aged 30, or thereabouts, and a nephew, Jack Curley, aged 28. From a scientific point of view, of course, this was unfortunate.

The physical proportions of the Vancouver Indians are rather less than those of the individual of the Algonkian stock. The Vancouver Indian is shorter and slighter of build, but on the whole, stronger and more hardy. He is certainly more active as well as more alert than the Algonkian. In their native haunts, the men are fisherman, often going miles to sea in open boats in the search of whale and seal, which are captured by skillful rowing and spearing.

The Vancouver women are especially noted for their beautiful

blanketry, skill in weaving and dyeing. Some of the men also carve skillfully in ivory and wood. In common with most Indian tribes of the Northwest, the Vancouvers have elaborate ceremonial rites, family legends bound up with the family totem, and certain fiducial customs and habits, which are the sacred possession of the household to which they are attached. The totem and fiducial customs attached thereto pass down as a family coat-of-arms, as it were, by which the tribe is distinguished.

In point of intelligence, the Vancouver Indians surpassed any of the Indians we tested save only those boys and girls at the Indian schools who had for years been moulded by the influences and habits of whites. We, therefore, found these people easy to handle and instruct.

The Pigmies.—The group of people popularly known as the Pigmies whom we tested were made up of individuals from three tribes; three Batwas, two Batsubas and one Cheri Cheri; all were males. Their ages were uncertain. They were, however, boys, almost if not fully grown, though I think none was older than 25 years. It is claimed that no Pigmies had before crossed the Atlantic, and naturally they were of peculiar interest. Only two or three of the natives had ever before left Congo territory. The Pigmies were brought to the St. Louis Exposition by Rev. S. V. Verner, a missionary who had spent some years on the African coast, and had familiarized himself with the Pigmy language and social customs. Mr. Verner related that it required some energetic persuasion to induce these people to accompany him to St. Louis. The Pigmy tribes observed by Mr. Verner in the Congo lived a parasitic existence, following the large Kaffir tribes and feasting on their bounty or refuse. It is related that companies of Pigmies and dogs, intermingled, station themselves at reasonable distances from Kaffir feasts, spying with envious eyes the feasting banqueters. No sooner is an unwholesome piece of flesh cast aside by the Kaffirs than there ensues a scramble of Pigmies and dogs indiscriminately for the rejected prize. Whether all Pigmies stand so low in the scale of social culture we are unable to say, but it is held to be applicable to the group which we tested.

In physical appearance, the Pigmy presents no sign that might lead one to class him as of degenerate stock. Although not exceeding an American boy of twelve years in stature, his bodily proportions are good. Still, he is not robust nor capable of great endurance or extraordinary feats of strength. This inferiority, however, probably has its basis in habit, rather than in any innate physical incapacity. Active in play and frolic, and with a keen sense of

humor, the Pigmy is a thorough optimist. He really enjoys life, indeed, takes everything with such a degree of levity, that it was only with considerable effort that we were enabled to have him approach our tests with anything like the seriousness they demanded. Withal, the Pigmy is stupid and dense and apprehends meanings slowly and often incompletely. The hearing tests being very simple in character, however, were understood with a fair degree of apprehension, and I have reason to believe that the data are reasonably representative of the group measured.

The Patagonians—Tehuelche Indians.—I was successful in testing only four men of the group of Indians from southern Patagonia; their ages being respectively, 18, 24, 35 and 55 years. At home, the individuals on exhibition at the Exposition had been employed as herdsmen on the Patagonian prairies. They had learned the use of money and, furthermore the habit of rendering no service, no matter how trivial, without a money consideration. This necessitated a bribe of money before any measurements were possible.

Like many other of the Indian tribes, the Tehuelche are sullen and uncommunicative. Their cultural habits are primitive. Their habitation is a tent made of the skins of the llama or guanaco, sewed together so as to form a considerable sheet. This is then stretched across poles, with the edges spiked to the ground. Within this tent, the family cooks, sleeps and lounges. As there is no vent for the escape of smoke, and the floors are never scoured, filth and grime abound everywhere.

The Tehuelche are horsemen and skilful in the use of the bolo, a triple thong loaded at the end with stone weights—which is thrown great distances with unerring accuracy. They are a large people, both men and women being tall and robustly built. With respect to the four individuals measured by us, no unusual difficulty was experienced in instructing them in the ways of the tests, but I question whether in grade of intelligence, they did not exceed the average of the Patagonian Indian.

PART I

THE UPPER LIMIT OF AUDIBILITY

CHAPTER II

HISTORICAL

THAT considerable individual differences exist amongst persons with regard to the faintest tone that can just be sensed is commonly recognized, but differences in the *range of hearing* are not so readily apparent. Helmholtz first called attention to the fact that the chirp of the cricket is sometimes wholly inaudible to people whose hearing is otherwise uneffected—who have experienced absolutely no diminution in hearing. Even after the fact was known that such individual differences really exist, the experimental determination of the range of such variations long awaited some device which would produce and accurately evaluate the sonorous stimuli.

Experiments with visual sensations present no such difficulties as are encountered by an investigator who works with sound. Among visual stimuli, qualitative characteristics are overt. They stand out in such a way as to be little confused by an individual with a normally functioning visual organ. Differences in color such as those between red and green, yellow and blue, or, indeed, yellow and red, are readily perceived, and at the same time differentiate certain qualitative effects to which there is no analogue in the field of audition. When one is affected with the sensation red, it has been determined once for all time, that the stimulus arises from a disturbance in the ether amounting to approximately 450 billions of vibrations to the second, and that the sensation blue corresponds to a disturbance of approximately 790 billions. But, among the higher orders of pitch, differences in tones as great as an octave are scarcely observed, even when they follow each other in immediate succession. Indeed, among comparatively low pitch values, the perception of tone differences is relatively uncertain. In truth, pitch differences stand out as variations in degree only, while color differences naïvely are differences in kind.

Coming to the question of accurate tone analysis, the physical difficulties are still more involved. What the prism has been able to do for the physicist in assisting him in establishing the wave-length

of any ray of light whatsoever, the resonators of Helmholtz and König do only very unsatisfactorily, in helping to fix the components of any tonal compound or establishing the pitch of a given unknown sound. The latter, indeed, must still be accomplished by complicated registering devices. Again, the nature of auditory stimuli is such as to make every unfamiliar tone in nature an almost wholly unknown quantity, which it becomes necessary to establish, empirically, always anew. And with a shrill tone, the empirical method alone suffices to fix the pitch even roughly.

Unfortunately, the importance of knowing the exact character of the stimuli employed has not always been appreciated by investigators in the field of hearing. Especially is this to be regretted in the reports of investigations on the limits or the range of audition. It thus happens that on account of a diversity of statement and lack of precision in the definition of the tones employed, it is wholly impossible to compare the data of different investigators. But they serve to emphasize the futility of any research in the field of hearing unless the physics of the problem involved has first been clearly worked out. Some figures relating to the upper threshold of hearing, given out by different investigators, will serve to illustrate what I have just indicated.

Blake and Appunn[1] who are among the foremost investigators of the upper limit of audibility, think the human ear to be sensative to tones of 50,000 or 60,000 double vibrations to the second. Preyer[2] placed the extreme upper limit at 40,000 vibrations; König,[3] with the use of short sounding rods and a modification of the Galton whistle, got results substantially in agreement with those of Preyer. With a Galton whistle blown by a constant air blast, Zwaardemaker[4] believed he could produce audible tones whose vibration rate exceeded 33,000 to the second. But all these data were called in question by Melde,[5] who pointed out that previous investigations were valueless because of instrumental errors. Melde's objective experiments with different makes of instruments led him to believe that no ear is sensitive to tones above 24,000 double vibrations to the second. Melde's investigations were repeated and elaborated by Schwendt,[6] who reached the conclusion that with the Galton whistle,

[1] *Annal. d. Phys. u. Chem.* **64**: 409. 1898.

[2] "Die Grenzen der Tonwahrnehmung" (English trans.), *Proc. Mus. Assn.*, 1876, pp. 1–32.

[3] *Annal. d. Phys. u. Chem.* **69**: 626–66, 721–38. 1899.

[4] *Arch. f. Ohrenhk.* **35**: 30. 1893; *Ztschr. f. Psychol.* **7**: 10. 1894.

[5] *Pflüger's Arch.* **71**: 441. 1898; *Annal. d. Phys. u. Chem.* **67**: 781–793. 1899.

[6] *Pflüger's Arch.* **75**: 346–64; **76**: 189–91. 1899.

audible tones of greater vibration frequency than 22,000 can not be produced. However, with an instrument modeled after the type of the steam whistle (Edelmann's), Schwendt[7] found that where greater intensities of air blasts might be employed, a tone of the value of 49,000 double vibrations might still be heard. With the same whistle, Edelmann[8] put the upper limit at 50,000 double vibrations. By a singular method Stumpf and Meyer,[9] in which some König forks and an Appunn Galton whistle were graduated by a method of difference tones, believed a greater vibration rate than 20,000 inaudible. Still more recently, after some extended objective experimentation with a Galton whistle of the Hawksley pattern, Dr. Charles Myers[10] concluded, at least so far as the Hawksley whistle goes, that tones above 24,000 double vibrations to the second can not be made of such an intensity as to be audible, nor indeed measured by any known means.

It is scarcely necessary to enter into a detailed discussion of the factors responsible for such wide discrepancies in results as these shown between instrument makers on the one hand and scientific investigators on the other. A review of the literature relating to this work, notwithstanding, forces the conviction, that the variations are due to instrumental differences almost wholly—being complicated by the failure to allow for the physical and physiological factors involved in the tests conducted. Much of the early work suffers from inefficient methods of arriving at the vibration frequencies of the tones that have been employed in making the physiological measurements. A great deal of the later work on the upper limit of hearing is of the same character. If we add to this difficulty the fact that the physiological value of tones for the ear has been ignored, it is not improbable that most of the differences would be accounted for. In keeping with this conviction are the recent investigations of Wien and Zwaardemaker.

Wien[11] and Zwaardemaker and Quix[12] have shown that the ear is most sensitive to tones whose pitches are of the middle values, those lying roughly within the range covered by conversational speech (400 D. V. to 4000 D. V.). Both above and below these values, the ear's sensitivity is found to diminish rapidly. Indeed, as early

[7] *Verhandl. d. Naturforsch. Gesellsch., Basel,* **12**: (1900); *Arch. f. Ohrenhk.* **48**: 1. 1900.

[8] *Annal. d. Phys.* **2**: 469. 1900; *Ztschr. f. Ohrenhk.* **36**: 330. 1900.

[9] *Annal. d. Phys. u. Chem. N. F.* **61**: 760–79. 1897.

[10] "The Pitch of Galton Whistles," *J. of Physiol.* **23**: 417. 1902.

[11] *Pflüger's Arch.* **97**: 1. 1903.

[12] *Arch. f. (Anat. u.) Physiol. (Suppl.)*, 1902, 367–98; also *Ztschr. f. Psychol., u. s. w.* **33**: 407. 1904.

as 1878, Helmholtz (Tonempfindungen) pointed out that the ear's range of sensitivity could not be safely divorced from the factor of the intensity of the tonal elements, but the importance of this fact, as related to the upper and lower thresholds of audition, has until recently received little thought. Scripture and Smith[13] in reviewing the factors involved in the wide variations discovered by those who have investigated the ear's range of sensibility again called attention to the importance of the intensity factor and suggested that perhaps the differences in recorded experimental results might be explained on this basis. Some experiments with the Galton whistle, in which various degrees of wind pressure were employed convinced them that if the intensity of the stimuli could be made sufficiently great, the ear would be found to be sensitive to tones whose vibration frequency exceeded 50,000 or even 55,000 D. V. It must be confessed, however, that their empirical evidence for such a conclusion is not particularly convincing.

In the light of recent experimental results, it would not be overconfident to believe that such wide discrepancies as the figures from different observers show would largely disappear were it possible to reckon and allow for the two factors just indicated—the physical, concerned with graduation and intensity, and the physiological, concerned with the ear's relative sensitivity. Both of these factors are so interrelated in the historical data to be considered, that it is impractical to attempt to separate them.[14] This condition comes about partially at least because no uniform type of instrument has been employed for measuring the upper threshold of hearing. Appunn,[15] Preyer,[16] and Koenig[17] used small tuning forks in which the instruments themselves possess certain physical limitations confining the possible intensities of the tones to very narrow limits. Koenig's "rods" possess the same deficiency. It appears that all of these instruments uniformly were assigned tonal values altogether too high.

[13] See "Highest Audible Tones," *Studies from the Psychological Laboratory of Yale University*, 1894, p. 105.

[14] To Schwendt particularly do we owe a method for evaluating the vibration frequencies of tones, which is wholly independent of the experimenter's auditory sensitivity. As Schwendt remarks, it is a method that may be employed equally well by a person wholly devoid of hearing, and consequently eliminates so far as such a thing is possible, the element of the personal equation. The method consists of an adaptation of the Kundt dust figures to tubes of small bore and sound waves of extremely small extension. See *Annal. d. Phys. u. Chem. N. F.* 61: 760–69. 1897.

[15] *Annal. d. Physik u. Chem.* 64: 409. 1898.

[16] *Pflüger's Arch.* 71: 441. 1898; *Wiedemann's Annal.* 51: 683. 1894; 52: 238. 1894.

[17] *Pflüger's Arch.* 75: 346. 1899.

Melde,[16] who put to experimental test the pitch values assigned to the tuning forks used in Preyer and Appunn's experiments, entirely discredited them. His results were later confirmed by Schwendt.[17] The Appunn fork marked (g^8) 50,000 (double vibrations) was found to have a vibration rate of only 13,157 D. V. The pitches of the remaining forks of the series were overstated to about the same degree.

What has just been said of the tuning forks applied with equal force to the sounding rods of König. His highest pitched rod, according to the optographic measurements of Melde, gave a tone of (f^7) 21,845 D. V., although König had assigned to the same rod a value of 40,000 D. V. Much of the error, no doubt, arose on account of the method used for assigning the pitch values to the different forks and rods. Preyer, König and Appunn believed that forks could be graduated with sufficient accuracy for ordinary scientific purposes, with the unaided ear. According to Preyer,[18] practised musicians can distinguish with certainty a difference in pitch amounting to one-half a vibration between the limits of "C" and "c^2." Were it possible for practised observers to discriminate tonal differences as accurately for all parts of the hearing scale, the graduation of instruments for measuring the upper limit of hearing might well be made by some such subjective method as these investigators employed. But the perception of interval is extremely deficient for tones above "c^8," as the experiments of König[19] with sounding rods and those of Preyer[19] with tuning forks have pointed out. With tones in the sixth octave an interval of a fifth is scarcely observable, while for tones in the seventh octave and above an interval of an octave passes unnoticed even by musical ears. As Schwendt has well remarked, it is not improbable that the production of audible tones of a pitch exceeding 25,000 vibrations to the second, with a tuning fork or rod is a physical impossibility owing to the extreme weakness of tones coming from such sources. Where the forks are made as small as those must be to give a tone above 25,000, the energy given out is much diminished. Schwendt further pointed out that, even were their production possible, no known means exists for determining the vibration rate. The methods in use for determining the vibration frequencies of tones are wholly inapplicable to tones of so small energy value as these. Indeed, Schwendt found the resonance method inapplicable for the forks and rods of a vibration frequency exceeding 15,000.

[18] "On the Limits of the Perception of Tone" (trans.), *Proc. Musical Assn.* 1896–7, pp. 1–32.

[19] Helmholtz, "Tonempfindungen" (4th ed.), p. 147.

By far the most common device for measuring the upper limit of hearing has been some form of the Galton Whistle. This type of threshold-whistle,[20] devised by Sir Francis Galton, is constructed on the model of the closed organ pipe, with vibrating lip and resonance cavity. In a closed organ pipe, Helmholtz and also Lord Rayleigh[21] found that theoretically, at least, the vibration frequency is a definite function of the length of the resonance cavity. Knowing the velocity of sound in air at the temperature prevailing "V_s," the length of the resonance cavity "L," the vibration frequency "N" in double vibrations may be computed directly from the formula

$$N = \frac{V_s}{4L}.$$

In point of fact this theoretical formula is not wholly valid even for closed pipes of relatively large dimensions as has been experimentally demonstrated by Savart,[22] Liscovius and Wertheim[23] and others and, indeed, the formula has been shown to be wholly inapplicable to pipes of small bore.[24] Differences in the pressure of air blast employed, the ratio between the length and width of the resonance cavity, the dimensions and shape of the mouth slit, together with the materials of which the whistles are made, all have been proven to be extremely important factors in determining the pitch of Galton whistles as well as all other closed pipes of this variety.

As the diameter of the resonance cavity increases, the tone deepens but, on the other hand, the pitch becomes more acute as the wind pressure becomes greater. Such considerations make impossible any mathematical formula generally applicable to threshold pipes. It has been found, moreover, that no matter how painstaking and skilful the construction in the attempt to duplicate a threshold whistle differences are certain to result, which make it necessary to graduate objectively each whistle independently.

In the experiments of Stumpf and M. Meyer,[25] in which Galton whistles were used, the graduations were also made subjectively. These investigators depended on the observation of difference tones. By blowing two whistles, whose pitches differed by about 2000 double vibrations to the second, simultaneously, a difference tone resulted whose pitch these investigators believed they could place

[20] This whistle is described in Galton's "Inquiries into Human Faculty," p. 38.

[21] *Phil. Mag.* **22**: 344. 1879.

[22] Wüllner's "Experimental Physik," Bd. 2, p. 324.

[23] *Op. cit.* Bd. 1, p. 886.

[24] Vid. Myers, *J. of Physiol.* **28**: 417. 1902.

[25] *Annal. d. Phys. u. Chem.* **61**: 760–79. 1897.

accurately by ear. Then, by increasing the pitch of each whistle alternately, graduations were made until the point was reached where the tones faded entirely. A similar method was pursued with the König tuning forks and the sounding rods.

Certain serious criticisms, however, have been offered against the method. In the first place, difference tones are difficult to recognize at all times and one is never quite certain whether the difference tone is the difference between the vibration frequencies of the fundamentals of the two tones employed or of their octaves, or, perhaps, of the second upper partials. It depends altogether upon the relative intensities of the various components, factors indeed, of which we are never quite certain in the production of very acute tones. Helmholtz[26] observes that while the method of difference tones is possible with pitches whose vibration frequencies fall below 10,000, for values higher than this the method is extremely uncertain. In point of fact when Stumpf and Meyer's graduations were put to experimental test they were shown to be not at all reliable. Employing a resonance method for evaluating the pitches of the instruments used by these investigators, Melde[27] found that the graduations were not accurate to within 10,000 double vibrations for the shriller tones—those of f^7 and above.

There has been on the market, during recent years, an improved form of threshold whistle devised by T. L. Edelmann.[28] It is asserted that this instrument overcomes the objections put against the older Galton form. Edelmann believes that with his whistle tones of 110,000 D. V. can easily be produced and the vibration frequencies fixed; tones, to be sure, which are far too high for any ear to sense. The mechanism of the whistle is such as to consume considerably more energy in its operation than the ordinary Galton type and it likewise gives out a tone whose intensity is many times in excess of that given out by the Galton whistle. Zwaardemaker and Quix[29] discovered that the upper threshold of hearing might be raised a major third by increasing the intensity of the tone 1,000 times, and Wien thinks that it may be raised at least a full octave if the intensity can be increased 10,000 times.[30]

[26] "Tonempfindungen" (4th ed.), p. 203.

[27] Über die verschiedenen Methoden der Bestimmung der Schwingungszahlen sehr höhen Töne, *Annal. d. Phys. u. Chem.* 67: 781–93. 1899.

[28] This whistle, together with the methods for its graduation, is fully described by the inventor in an article in *Annal. d. Physik* (N. S.) 4: 469–82. 1900.

[29] *Ztschr. f. Psychol.*, u. s. w., 33: 407. 1904.

[30] *Pflüger's Arch.* 97: 1. 1903.

These conclusions confirm the conviction of Scripture and Smith, referred to above.[31] Exactly in the same direction point some of the experiments of Dr. Chas. Myers, in which an Edelmann whistle with different degrees of wind blast was used. His statement of the facts is so convincing that I quote his own words: "When the wind pressure was 30–35 mm. of water, a very faint quivering note was heard. The note rose gradually until a wind pressure of 140 mm. of water was reached when the tone disappeared. Increasing the pressure 100 mm. the tone was again audible, and, at a wind pressure of 800 mm. of water, the tone was at least an octave higher." With a pipe length of 1.3 mm. and mouth width of 0.75 mm., employing the Schwendt dust figures for evaluating the pitch numbers, Meyers got the following significant figures: When the wind blast, measured by water pressure was 36 mm., the vibration frequency was 5,673.

With a water pressure of 109 mm. the vibration frequency was 10,942
With a water pressure of 680 mm. the vibration frequency was 23,315
With a water pressure of 800 mm. the vibration frequency was 28,332

The last figure exactly corresponds to that given, for the same adjustments, in the chart which the makers sent with the Edelmann whistle used in the experiments to be detailed in this writing. This tone and many much higher were easily heard not only by myself, but also by a majority of my adult subjects. There is no question but that the fundamental objection to the Galton whistle used by Zwaardemaker, Stumpf, Dr. Chas. Myers and others, as well as to the tuning forks and sounding rods, lies in this, that the tones produced are too feeble, not only to cause a disturbance of the lycopodium powder in the dust tubes, but also to reach the physiological threshold of the auditory end organs for tones of the upper pitches.

So much for the literature referring specifically to the physics and physiological factors of the problem. Now, let us look for such sensory differences as have been discovered.

In the light of the sources of error mentioned above, the sensory data thus far collected are almost hopelessly bemuddled.

Zwaardemaker,[32] perhaps, has collected more data of individual and age differences as regards the upper limit of hearing than any one else, but his results are not even comparable among themselves. In some of his experiments, a form of the Galton whistle was employed, graduated by the Stumpf-Meyer method. In still other of

[31] *Loc. cit.*, p. 108.
[32] *Annal. d. Phys. u. Chem.* (N. F.) 61: 760–79. 1897.

his experiments, the pitch values of the different whistle lengths were fixed by comparing the tones given out with those of the König rods or the König tuning forks. The untrustworthiness of both of these methods of making graduations has been pointed out above. Zwaardemaker's "e^6," a tone which many of his subjects heard distinctly was found[33] to be wholly fictitious.

Regarding the upper limit of hearing of whites, the literature is not at all scant. But even were it possible to separate out the data in which the instrumental defects have been least prominent, it would still be difficult to draw comparisons. Without exception, the distrbution of cases has been omitted in the data presented. Most of the work on the upper range of hearing has been carried on for the purpose of determining age differences. It has been pretty well established that the upper limit of hearing contracts with increasing years of life. Zwaardemaker,[34] Cuperius,[34] Alderton,[35] Myers,[36] and others have contributed rather convincing data on this phase of the problem.

The results obtained are so significant as to justify the inclusion of tables summarizing them:

	Zwaardemaker[34]		*Cuperius*[37]	
Ages	Whistle Length	Pitch	Whistle Length	Pitch
Under 10 yrs.	1.22 mm.	e^7		
10–20 "	1.39 "	dis^7	1.08 mm.	f^7
20–30 "	1.39 "	"	1.19 "	e^7
30–40 "	1.58 "	"	1.31 "	"
40–50 "	2.23 "	cis^7	1.39 "	dis^7
50–60 "	2.93 "	h^6	2.08 "	cis^7
Over 60 "	3.03 "	cis^6	3.02 "	cis^6

Alderton reports as follows the examination of 500 individuals with the Gaton whistle:

For children up to 12 years—pipe length on the average .. 1.24 mm.
For adults—pipe length on the average .... 3.03 mm.

Dr. Charles Myers's[36] tests of Scotch children point in the same direction.

The Upper Limit of Audibility among Primitive Races.—So far as I have been able to discover, no measurements of this character save those of Myers and my own herein reported, have ever been

[33] Myers, *op. cit.*
[34] *Arch. f. Ohrenhk.* 35: 54. 1893; *Ztschr. f. Psychol.* 7: 11. 1894.
[35] *Arch. of Otology*, 23: 71. 1894; 25: 43. 1896.
[36] Report of the Cambridge Anthropological Expedition to Torres Straits, Vol. 2. 1903.
[37] *Ztschr. f. Psychol.* 7: 10. 1894.

made. In their work on the upper limit of hearing of the native Papuans of the Murray Islands, Rivers and Myers[36] used the Hawksley pattern of the Galton whistle. This was an instrument with an extremely small bore, such as to make it possible to produce very high pitched tones. Dr. Myers, who reports the hearing tests, was inclined to put little faith in the graduations of his instrument, a task which was performed after he had returned to England, so the data relative to sensory differences are given in terms of the length of the cavity of the whistle.[38] His results are presented so as to show at the same time race and age differences. I summarize them in the following table:

	Murray Islanders				*Aberdeenshire Folk*		
	No.	Age	Whistle Length		No.	Age	Whistle Length
Children	2	5– 9 yrs.	2.25 mm.	Children	4	5– 9 yrs.	1.97 mm.
	15	10–15 "	2.07 "		18	10–15 "	1.99 "
Adults	5	16–19 "	2.25 "	Adults	....	....	....
	9	20–29 "	3.00 "			20–29 "	2.22 "
	12	30–39 "	3.17 "			30–39 "	2.63 "
	9	40–49 "	3.53 "			40–49 "	3.19 "
	10	Over 50 "	4.68 "			Over 50 "	3.77 "

It appears from this table that for all ages the upper threshold of hearing of the Papuans is lower than for Scottish people of corresponding years. It is a conclusion that is significant, notwithstanding that the numbers tested for the several ages were small. More of this, however, in connection with the discussion of my own figures.

[38] Dr. Myers employed a number of methods in making the graduations of tonal values corresponding to the different cavity lengths in the tests. Chief of these are the resonance method and optographic method. See *J. of Physiol.* **24**: 417. 1902.

CHAPTER III

The Instrument and Its Graduation

I employed, for measuring the upper range of audibility, the Edelmann modification of the Galton whistle. It is probably too commonly known to require description.[1] It differs from the familiar Galton form, in being modeled after the pattern of the steam whistle instead of the closed organ pipe. In the opinion of Edelmann, this improved pattern possesses some marked advantages over the old form. In the first place, the different parts are constructed separately, allowing of finer work. The whistle cavity itself is a perfect cylinder, which makes it possible to turn it out very delicately on a lathe. Then, the whistle possesses a means whereby the width of the lip opening may be varied, so as to allow for the large quantity of air that must pass through it in producing low pitched tones, and still avoid the air puff with extremely shrill tones. In measurements with the Galton whistle this air puff, which accompanies very high tones, is extremely confusing especially to untrained subjects. Not infrequently a subject states that he is not certain whether he hears a tone or wind only. Dr. Myers[2] observes in connection with his work on the native Papuans in which the older Galton type of instrument was employed, that there was constant confusion between the perception of the sound and that of the air puff, which always accompanied it. While I do not think that this difficulty is entirely obviated by making the mouth width of the whistle adjustable, as in the Edelmann pattern, yet there is no question but that the Edelmann whistle is superior in this respect to the old Galton form. In my own experiments, I had never observed that any subject found difficulty in distinguishing between the accompanying air puff and the tone and, indeed, when the whistle was so far as 25 centimeters from the ear, almost no air puff was ever audible.

[1] Those not familiar with the instrument, I refer to the inventor's (Professor Edelmann's) able description and careful drawings to be found in the *Annalen der Physik* for 1900. 4 Folge, Bd. 2, S. 469. Those also unfamiliar with the Galton whistle may find a description of this instrument in Galton's "Inquiries into the Human Faculty," 1883, p. 275.

[2] *Op. cit.*, p. 4.

The manufacturers send out with each Edelmann[8] whistle a chart giving the pipe length, the mouth width, and the vibration frequency corresponding to each of some twenty different tones, ranging in pitch from that represented by a vibration rate of 6,000 to that represented by a rate of 50,000 double vibrations to the second. It is claimed that each whistle has been graduated independently and empirically at the factory, and that, for each tone, that mouth width was selected by trial and practise which would produce a note of optimum purity and strength.

In the chart sent out with the whistle which fell into my hands, it appeared that the graduations for those tones lying between e^6 and e^8 had been made with a uniform mouth width of 0.75 mm. With the whistle so adjusted, those tones lying in the region of e^6 were pure, clear and free from that peculiar harshness which results when a considerable quantity of air escapes with the tones. The contrary, however, was true when the whistle cavity was diminished for the production of tones in the region of e^8. These latter tones were decidedly harsh. This harshness was obviously due to the accompaniment of air puffs, which escaped with the tones. They stood out so prominently as to confuse even the most careful subjects, and must have proven a very distracting element to children, and especially to the primitive peoples. It therefore seemed advisable to vary the adjustment from that prescribed in the chart sent out with the instrument even if it would necessitate an entire re-graduation.

After careful experimentation with the assistance of Professor Woodworth, a mouth width was hit upon which give admirable results for all tones from e^5 upwards. Indeed, so free was the tone from wind blasts, that when the threshold range was passed, no auditory stimuli of any character were sensed as coming from the whistle. This mouth width was 0.55 mm. It chanced, however, that the resulting tone was predominantly the first overtone instead of the fundamental, but, since the fundamental tone was inaudible except for vibration rates between ten and fifteen thousand, it was thought not to be a particularly disturbing factor. All the measurements at the Exposition, consequently, except those where the upper limit was found to be extremely low, were made with a constant mouth width of 0.55 mm. This, to be sure, rendered the table which accompanied the whistle entirely worthless. A wholly new set of graduations must be made to meet the new conditions.

[8] The Edelmann whistle used in my tests was kindly loaned to me by the C. H. Stoelting Co., 38 W. Randolph Street, Chicago, for the double purpose of exhibition and experimentation.

To carry on such an extended series of experiments called for more time and more elaborate preparations than it was possible to institute at St. Louis. I therefore allowed this work to await my return to Columbia University after the Exposition had closed.

While collecting the data, the measurements were tabulated in terms of mouth width and pipe length, from which it was possible readily to transcribe them into terms of vibration frequencies, and into musical nomenclature when desirable. The graduation of the whistle was a difficult task. In the work of determining the vibration frequencies corresponding to the different pipe lengths employed in the actual test, several devices were tried with varying degrees of success. It was found especially difficult to devise any rotating system of sufficient speed and delicacy to register satisfactorily disturbances of a sensitive flame for such rapid vibration rates as those from 15,000 to 40,000 D. V. The optical method for registering vibrations used in physical laboratories, however, was tried for some of the lower pitches, but even here the figures were by no means wholly satisfactory, by reason of the inaccuracies in determining the speed of the rotating system, the sliding of parts, etc., etc.

The most satisfactory device for making the graduations, because the most accurate and objective, proved to be the "dust figure" method of Kundt, first adapted to the use of tubes of small bore by Schwendt.[4] The Kundt dust figures are illustrated and described in all general texts on acoustics; hence, they require no elaborate description in this place. The dust figure method is the one, moreover, which is employed at the factory for standardizing the Edelmann whistles before they are sent out. The modifications which are essential to adapt this method to tones as high as those employed for testing the upper limit of audibility are significant as to detail and procedure. It is unnecessary to enter here into a description of the mode of procedure in anything like a detailed way. Something requires to be said, however, with reference to some of the difficulties which are encountered.

One of the first essentials with regard to the dust figure method is that the tubes used for resonance chambers shall be of optimum dimensions. A series of tubes varying in length and bore are consequently necessary to secure satisfactory results. For evaluating the most acute tones, I drew out some very thin tubes to a bore of 2 mm. and a length of 26 mm.—just long enough to allow for the formation of five or six half-wave lengths, that is, for five

[4] *Pflüger's Arch.* **75**: 546. 1899.

crests and as many troughs. It is quite essential that a number of these artificial wave troughs and crests be formed if the work is to be at all delicate, since, in making the actual measurements of the length of the several waves, accuracy is enhanced if the span covered by several half waves is measured with the aid of calipers and the figure thus obtained divided by their number to secure the length of a single wave. Tubes with bores of from 6.0 mm. to 10 mm. and lengths from 100 to 250 mm. were used for tones of the sixth and the lower third of the seventh octaves (c^6–e^7), and still larger tubes for the tones of still lower pitch values. Just enough of the lycopodium powder, which had been previously carefully dried, to cover the bottom of the tube, was evenly distributed along its entire length. The tube was then slightly turned so as to raise the powder to one side. This facilitates the formation of dust figures, the aerial disturbance within causing the dust to fall, and while falling, to collect at the points of rarefaction within the resonance chamber.

In making dust figures, it is necessary that the resonance tubes be kept free from extraneous vibratory influences, else the resulting dust figures will be confused and impossible to interpret. To avoid jars of all kinds, I had the tubes carefully clamped between large pieces of cork, which took up most of the disturbances transmitted to them. Then to make as much as possible of the sound energy leaving the whistle enter the tubes, the whistle mouth was brought as close to the mouth of the resonance tube as possible, and, to further facilitate the movement of air, the ends of the tubes adjacent to the source of sound were flared into a funnel form whose widest diameter was about 15 mm. When everything proceeded favorably, satisfactory dust figures generally resulted in from ten to fifteen minutes, but failures and disasters were frequent. Indeed, much patience and repetition were required to secure perfectly reliable results, frequently as many as six or seven trials being necessary to get anything like a satisfactory measurement. It was essential that each graduation be the average of as many determinations as possible to eliminate chance results. My data, in every instance, are the average of five or more determinations.

Let us assume that the dust figures have formed in the resonance tube. Knowing the distance between two adjacent wave crests, it is a simple matter to compute the vibration frequency of the tone that gave rise to the dust figures. The result is accomplished directly by a simple formula,

$$N = \frac{V_a}{2L}$$

where "N" represents the vibration frequency, "V_a" the velocity of sound in air at the temperature prevailing at the time the measurement is made, and "L" represents one half wave-length, or the distance encompassed by two adjacent wave crests. The "V_a" implies a temperature correction. At 0° Centigrade, under ordinary barometric pressures for this latitude, sound has a velocity of 330.7 M. per second. To secure the corrected value of "V_a" for any given temperature, I used the well-known formula of Kayser and Kirchoff,[5]

$$V_a = 330.7 \sqrt{1 + 0.00376\, t^a}$$

During the summer of 1904, within doors on the shady side of a building the temperature varied (according to the United States Weather Bureau reports[6]), between 17° and 37° C. Our hearing tests, however, were made in a basement where the prevailing temperature was lower, and unfortunately we have no record of this during this period. Still the difference between this and the above, I think, does not amount to a figure to be significant. My corrections were made on the basis of the Weather Bureau statistics.[6]

In the sound-proof room of the Psychological Laboratory of Columbia University where the work of graduation was done, the temperature remained quite uniformly at 22.2° C., making the velocity of sound approximately 344 M. per second.

Temperature variations can not well be neglected in making tests for the upper limit of hearing with such a device as the Edelmann whistle, if results be sought which aim to be more than approximately correct. Taking the lower and upper extremes of temperature, during the days that my hearing measures were made, and making the necessary corrections, a whistle cavity length of 1.3 mm. and mouth width of 0.55 mm. would give a vibration frequency of 40,840 D. V. and 42,054 D. V. respectively. This variation is certainly sufficient to be quite significant, especially in view of the fact that tests on the different peoples were made during different seasonal conditions. With regard to most of the data relating to the Filipinos, the correction was especially necessary, because the season had so far advanced when these people were measured that the rooms had to be heated artificially, and the temperature, which was almost uniformly 22° C. differed markedly

[5] See Wüllner's "Experimental Physik" (1894), 1: 931.

[6] I was able to secure from the office of the U. S. Weather Bureau at St. Louis temperature and humidity readings taken at each hour of the day, for a period covering that included by the taking of the hearing records. From these figures I calculated the true value of "V_a" for each hearing record made.

from that prevailing during the hot summer weather when the data on Indians and whites was collected.

Conditions at the Exposition made it necessary to employ a wind blast supplied from the hand bulb, which accompanies the whistle. Some such constant pressure device as that of Whipple[7] was contemplated, but there was so much delay occasioned by the failure of the apparatus to arrive and the general equipment of the laboratory to be provided, that many of the tests of the upper range of hearing were made before such an equipment might have been installed. Consequently, to keep the conditions under which the tests were conducted as nearly uniform as possible, the hand bulb method of blowing the whistle was permanently adhered to. Edelmann holds that with a whistle of the type I used, the pitch of the tone is only slightly dependent on the wind pressure employed.[8] This statement, however, can be only partially true, and indeed is applicable only to a certain range of variation about the optimum wind blast for blowing it.

To investigate the influence of a variable wind blast to some extent, I improvised a wind pressure device which allowed of differences in the force of the blast. An ordinary wet spirometer, found in the Columbia University Psychological Laboratory, was weighted to the required wind pressure by loading it with slugs of iron; then, with an ordinary foot bellows, the quantity of air in this reservoir was kept constant. As in all such experiments, a water manometer or U-tube, was inserted in the lead as close to the whistle as convenient to measure the pressure of the air blast passing into the whistle. But before allowing the air to pass through the whistle, it was made to flow through a drying device; a bottle filled with the crystals of calcium chloride, by which the moisture was, so far as possible, removed inasmuch as moisture in the air tends to interfere seriously with the formation of the lycopodium dust figures in the resonance chambers.

The cavity length of the whistle being 1.3 mm. and mouth width 0.55 mm., with a constant wind pressure indicated by 40 mm. of water in the U-tube, the resulting tone was too faint and weak to produce satisfactory dust figures. It sounded of uncertain pitch and was by no means pure.

When the wind blast showed 100 mm. of water in the U-tube, the tone was clear but observably lower than when the whistle was blown by the rubber bulb. With the wind pressure increased to 500 mm. of water, the tone came forth clear and piercing. My

[7] "A Compressed Air Device, etc.," *Amer. J. of Psychol.* **14**: 107. 1903.

[8] *Annalen d. Physik,* 4 Folge, **11.** 1900.

subjective judgment was that the pitch was the same as that produced by the use of the bulb.

The table below shows the result, in terms of wave lengths and vibration frequencies, for a number of different wind pressures employed:

Wind Pressure: mm. of water	Wave Lengths in mm. Average of 5 determinations	Pitch Values D. V.
40	A faint tone—too weak to produce dust figures	
100	16.268	21,330
500	8.33	41,217
1,000	8.724	39,460
Rubber bulb	8.428	40,840

These averages were obtained from the following individual determinations:

Pressure—100 mm. of Water

3 crests measured	23 mm.	Wave length	15.34 mm.
2	17		17.00
2	19		19.00
3	22		14.66
3	23		15.34
		Average wave length	16.248 mm.

500 mm. of Water

5 crests measured	21 mm.	Wave length	8.4 mm.
4	15		7.5
4	18		9.0
6	25		8.34
5	21		8.4
		Average wave length	8.33 mm.

1,000 mm. of Water

4 crests measured	19 mm.	Wave length	8.5 mm.
6	26		8.66
6	23		7.66
5	22		8.8
4	18		9.0
		Average wave length	8.524 mm.

The Bulb

5 crests measured	19 mm.	Wave length	7.6 mm.
4	17.5		8.75
6	25		8.33
6	26		8.66
5	22		8.8
		Average wave length	8.428 mm.

These figures are in general in agreement with those obtained by Dr. Charles Myers, in investigating a similar problem with the

Galton whistle. It is to be noted, however, that a wind pressure of 1,000 mm. of water, gave a tone which is actually lower than that produced by a wind pressure of 500 mm. of water, a fact which does not accord with Dr. Myers's[9] experimental conclusions. His experiments lead him to believe that the pitch of the whistles increases regularly with increase of air blast. The difference in favor of the lower wind pressure found by me, I believe, however, is not significant in that I do not think it exceeds the limits of the accuracy of the method. It is to be further noted that with the bulb, the figures do not differ materially from those with a wind pressure of 500 mm. and 1,000 mm. So far as I was able to determine, the bulb gives approximately a pressure of 800 mm. of water though with a pressure of so short duration it is difficult to evaluate accurately the total force given out, with the means at my command.

Inasmuch as in all my investigations the bulb supplied the wind blast, it is the graduations in which the same source of wind pressure was used that concern us chiefly. Indeed, for this reason, in all of the work of standardizing the instrument, from which the tables to follow were made, the rubber bulb alone was employed. When using the hand bulb in the making of the graduations, an effort was made to reproduce as nearly as possible the conditions as they obtained in taking the original hearing records. That the conditions were more than approximately reproduced and, moreover, that with the use of the bulb, fairly constant conditions can be maintained from day to day, is borne out by the rather uniform character of the data secured. Were one unable to give relatively constant and uniform blasts to the whistle in blowing it with the hand bulb, some marked differences in the vibration frequencies of the tones produced would result, and would show in the dust figures. It is significant that such was not found to be the case, and that no greater differences in the character of the dust disturbances were experienced when the hand bulb supplied the air than when the air came from a uniform and constant pressure source, as is shown in the foregoing tables. To illustrate this point, I shall present some typical measurements in which the hand bulb was employed. As too much space would be required to present the individual measurements for the graduations of the whole series of whistle lengths used in the original tests, I will content myself with two samples selected at random.

In the following series, the length of the whistle bore measured 1.5 mm., the mouth width being 0.55 mm.:

[9] "The Pitches of Galton Whistles," *J. of Physiol.* 28: 417. 1902.

2 crests measured	9.2 mm.	Wave length	9.2 mm.
12	57.1		9.52
12	52.81		8.8
20	87.34		8.73
14	65.41		9.33
		Average wave length	9.116 mm.
		Vibration frequency	37,560 D. V.

In the next series, the cavity length of the whistle was 2.2 mm., the mouth width remaining the same as in the preceding experiment:

2 crests measured	16.0 mm.	Wave length	10.66 mm.
4	22.3		11.15
9	44.1		9.08
6	31.2		10.04
3	15.4		10.26
		Average wave length	10.45 mm.
		Vibration frequency	30,270 D. V.

These two sets of measurements are in every way typical of all that were made and indicate about the same degree of variation between the individual determinations as was experienced on the average. The same procedure, as in these samples, was followed for every whistle length employed in the original measurements. The accompanying table gives the vibration frequencies corresponding to each whistle length as empirically determined by aid of the Kundt-Schwendt resonance method.

In this table the distance between the lips of the whistle remained uniformly at 0.55 mm. The average wave-length of the several determinations has been omitted in each case since it would afford no information vital to an interpretation of the figures presented:

Length of whistle cavity in mm.	Vibration Frequencies (Complete Vibrations)	Length of whistle cavity in mm.	Vibration Frequencies (Complete Vibrations)
1.2	42,960	2.5	28,048
1.3	40,840	2.6	27,448
1.4	39,220	2.7	26,854
1.5	37,560	2.8	26,264
1.6	36,360	2.9	25,724
1.7	35,100	3.0	25,212
1.8	34,000	3.1	24,754
1.9	33,060	3.2	24,196
2.0	32,180	3.3	23,020
2.1	31,170	3.6	22,217
2.2	30,270	3.8	20,973
2.3	29,508	4.0	18,490
2.4	28,766		

CHAPTER IV

Data Collected on the Upper Limit

During the earlier months of the Exposition, while we were getting our bearings, equipping our laboratories, and installing our apparatus which was somewhat tardy in arriving, we spent our time amusing the public and, incidentally accumulating data on some few tests. For the most part we limited ourselves to a single test and measured as many individuals as we could in this one particular only. In consequence, I was enabled to secure considerable material relating to the upper threshold of hearing. Unfortunately these data had to be secured under somewhat unfavorable conditions, in that the test was always made in the presence of a crowd. The sound room had then not yet been completed and there were many distracting noises that might have tended to distort the results to some extent. On the whole, notwithstanding, I believe the data satisfactory, since a comparison of this material with some secured on whites in the sound room showed no significant differences.

The individuals were tested one at a time. The Edelmann whistle was held twelve inches from the subject's ear and blown; the other ear meanwhile being closed by pressing the tip of the finger into the auditory meatus. At first the pipe was so adjusted that a tone resulted whose pitch was so low as to be easily sensed by all ears. The pitch was then gradually raised until a point was reached where the tone was no longer audible. A reading was then taken and recorded for the last audible sound. Beginning with an inaudible tone, the pitch was now lowered until it could again just be sensed and this whistle length recorded. The average of the two tabulations, if a difference existed—and there usually did—was taken as the measure of the upper limit of the person tested. Each ear was tested. Almost without exception, the right ear was the one first examined.

In the measures on primitive peoples, the procedure was in all respects essentially the same as just outlined, except that the tests were made within a specially constructed booth.[1] Although this

[1] This booth was constructed in one corner of a room of our suite, which had been closed to the public, being set apart by us for making such measurements as required privacy. The dimensions of the booth were approximately six by nine feet, and seven feet in height. On two sides the heavy stone and

room was not completely sound-proof, it did exclude extraneous noises sufficiently well to keep the subject free from distractions. To contribute still further to this same end, the person tested was kept in the dark and his back turned to the experimenter, in order, so far as possible, to exclude visual stimuli and allow the subject's mind to concentrate wholly upon the auditory sensations presented to him. Moreover, the subject was seated in a chair, in as comfortable a position as possible. In other words, I attempted to make the external conditions as suitable as could conveniently be done for sensing the auditory stimuli and consequently securing the most nearly normal results.

By way of check, a record was made of my own hearing immediately following that of each individual tested. Conditions made it necessary for me to make personally the test of my own hearing. Still I do not think that the source of error arising from this method is really significant. Of course, the element of expectancy was something of a factor so that there might have entered into the experiments auditory images which it were easily possible to confuse and mistake for the stimulus at a time when it was really inaudible. I have, however, practically no auditory imagery, at least, I have never been able to observe any in myself, so it is scarcely possible that images of sufficient intensity to be confused with even faint stimuli should have arisen under the circumstances just noted. In any event, the factors concerned with the personal test did not vary from day to day or from hour to hour, and hence are not significant on the whole. In this connection may be mentioned the need for this check, discovered during the time the tests were being made. It frequently occurred that the whistle became partially clogged with bits of rubber, or other matter coming from the inside of the rubber bulb. This clogging had the effect of lowering the pitch of the upper tones from a fifth to an octave, although otherwise no apparent change in the character of the tones resulted, so that had it not been for the personal check-test, the subject would have received an unfairly high rating.

brick walls of the building served to exclude the most penetrating sounds. Although the remaining sides were of wood, the walls were double, the space of about four inches between the two being filled with sawdust. Sawdust to the depth of six to eight inches also covered the roof while the whole booth rested in a bath of sawdust in order to exclude any sounds which might be conducted into it through the cement floors of the building. Entrance was made through a single padded door, and the sole illumination came from an incandescent electric bulb which was suspended over the apparatus. The arrangement was such as to exclude extraneous sounds entirely for all practical purposes.

It is unnecessary to name all the factors and considerations which entered vitally into the making of the tests, but there is still one which requires to be mentioned. This relates to the ear's susceptibility to fatigue. Observers are unanimous in their experience with respect to this point. Professor Seashore[2] has remarked in connection with his audiometer that to be satisfactory for testing children, owing to the presence of fatigue, a device must be employed which will make it possible to complete the test in not to exceed two minutes. Especially with subjects who are unaccustomed to making introspective observations, it is found that tones die out and are inaudible long before threshold values are reached. Particularly is this true where continuous tone devices are employed in making auditory measurements such, for example, as the tuning fork, the sounding rod, or the Galton or Edelmann whistle, blown by some constant and continued air supplying device. For this very reason such devices and means for testing the range of audition are unserviceable. The Edelmann whistle blown by means of the bulb with its short, quick sound obviates all this difficulty. It is a difficulty, too, which can not be overlooked with safety, especially in dealing with children and primitive peoples.

The Measurements.—We shall now turn directly to the data regarding racial differences in the upper limit of hearing. In Table I. are presented the figures representing the averages for both the right and left ears. In the first column are indicated (1) the number of individuals constituting each group examined; and in parallel columns; (2) the averages; (3) the average of the deviations from each average; and (4) the standard deviation, of each group. From these data it is possible, without difficulty, to compute directly any of the different variability coefficients desired, and in consequence, the reliability of each average, and the probability of a difference between any two groups. Owing to the fact that among the Filipinos, the Pigmies, Patagonians and Cocopa, there were no women tested, the data have not been separated so as to show the influence of sex, except that relating to whites.

In tables II. and III. the individual records are distributed, so as to present in parallel columns a picture of the distribution of the individuals of each group examined. These tables represent the figures for both the right and the left ears. In Table IV. is presented a distribution of the cases according to age, for the three most numerous groups measured. These again have been placed in parallel columns to afford a more ready comparison, and to give

[2] *Univ. of Iowa Studies*, 2: 55. 1899.

in pictorial form the relations which the different groups sustain to each other in this respect. For the smaller groups, the ages will be presented in connection with their discussion.

TABLE I

UPPER LIMIT OF AUDIBILITY

Racial Differences as Shown by Averages

	No.	Right Ear			Left Ear		
		Average	A. D.[3]	S. D.[4]	Average	A. D.[3]	S. D.[4]
Whites...........	156	32,285 D. V.	2271	2344	33,087 D. V.	1891	2482
Indians...........	63	31,975 "	2190	2663	31,580 "	2460	3028
Filipinos.........	97	29,916 "	1755	2180	29,886 "	1737	2089
Cocopa...........	10	32,123 "	827	977	31,794 "	1408	1566
Ainus.............	7	28,846 "	1666	1873	29,529 "	2946	3199
Vancouvers......	7	28,269 "	1209	1413	27,571 "	819	852
Pigmies..........	6	33,223 "	2071	2468	34,081 "	3212	3428
Patagonians.....	3	30,240 "	3240	3551	28,630 "	2366	2592

TABLE II

RIGHT EAR—UPPER LIMIT OF HEARING

Distribution of Individual Cases

Vibration Frequency	Whistle Length	Whites	Indians from School	Christian Filipinos	Cocopa Indians	Ainu	Vancouver Indians	Pigmy	Patagonian Indians
42,960	1.2	1	—	—	—	—	—	—	—
40,840	1.3	0	—	—	—	—	—	—	—
39,220	1.4	3	1	—	—	—	—	—	—
37,560	1.5	8	—	—	—	—	—	1	—
36,360	1.6	9	6	—	—	—	—	—	—
35,100	1.7	10	6	2	—	—	—	1	1
34,000	1.8	15	4	2	1	—	—	—	—
33,060	1.9	18	6	4	2	—	—	1	—
32,180	2.0	26	6	11	1	—	—	1	—
31,170	2.1	20	12	14	4	1	—	1	—
30,270	2.2	18	8	20	—	2	1	1	—
29,508	2.3	6	3	10	—	1	1	—	—
28,766	2.4	6	5	5	—	—	2	—	1
28,048	2.5	7	3	10	—	1	1	—	—
27,448	2.6	3	1	2	—	1	—	—	—
26,854	2.7	3	1	5	—	—	2	—	1
26,264	2.8	2	1	3	—	—	—	—	—
25,724	2.9	1	1	5	—	—	—	—	—
25,212	3.0	—	—	—	—	1	—	—	—
24,754	3.1	—	—	—	—	—	—	—	—
24,196	3.2	—	1	1	1	—	—	—	—
23,020	3.4	—	1	—	—	—	—	—	—
22,217	3.6	—	1	—	—	—	—	—	—
20,973	3.8	—	—	—	1	—	—	—	—
18,490	4.0	—	—	—	—	—	—	—	—

[3] A. D.—Average Deviation.

[4] S. D.—Mean Square Deviation.

TABLE III

LEFT EAR

Distribution of Individual Cases

Vibration Frequency	Whistle Length	Whites	Indians from School	Christian Filipinos	Cocopa Indians	Ainu	Vancouver Indians	Pigmy	Patagonian Indians
42,960	1.2	—	—	—	—	—	—	—	—
40,840	1.3	—	—	—	—	—	—	—	—
39,220	1.4	1	1	—	—	—	—	1	—
37,560	1.5	8	2	—	—	—	—	1	—
36,360	1.6	3	2	—	—	—	—	—	—
35,100	1.7	9	5	—	—	—	—	1	—
34,000	1.8	14	8	1	—	—	—	—	—
33,060	1.9	18	6	6	1	1	—	—	—
32,180	2.0	9	4	11	—	2	—	—	1
31,170	2.1	11	11	21	3	—	—	2	—
30,270	2.2	5	3	10	1	—	—	1	—
29,508	2.3	2	11	13	1	—	—	—	—
28,766	2.4	5	0	7	—	1	2	—	—
28,048	2.5	2	4	5	—	—	1	—	—
27,448	2.6	—	1	5	—	—	—	—	1
26,854	2.7	—	1	5	—	1	4	—	—
26,264	2.8	—	1	6	—	—	—	—	1
25,724	2.9	—	3	2	—	—	—	—	—
25,212	3.0	—	—	—	—	—	—	—	—
24,754	3.1	—	—	1	—	1	—	—	—
24,196	3.2	—	1	—	—	—	—	—	—
23,020	3.4	—	—	—	—	—	—	—	—
22,217	3.6	—	—	—	1	—	—	—	—
20,973	3.8	—	1	—	—	—	—	—	—
18,490	4.0	—	—	—	—	—	—	—	—

TABLE IV

TABLE SHOWING THE NUMBER OF PERSONS OF EACH AGE OF THE THREE MOST NUMEROUS GROUPS OF PEOPLE MEASURED

Ages	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Whites	5	6	10	8	14	12	14	9	13	11	12	10	19	6	7
Indians (School) ...	12	11	16	12	4		2	2	1	1		2		1	3
Filipinos	3	1	8	16	20	14	12	7	5	5	2	2			1

Average age: Whites, 23 years, 5 months; Indians, 19 years, 2 months; Filipinos, 21 years, 1 month.

Reference to Table I. shows that of Whites, the records of 156 individuals were included in this study. Owing to some rather significant changes, that occur in the range of audibility during the earlier and later years of life as has been already indicated by the studies of Zwaardemaker,[5] Alderton, and others, it was thought advisable to include in these data only the records of those in early manhood and womanhood, those individuals whose ages ranged

[5] See Alderton, *Arch. of Otol.* **23**: 171. 1894; **25**: 45. 1896; also Zwaardemaker, *Ztschr. f. Psychol.* **7**: 10. 1894, and *Arch. f. Ohrenhk.* **32**: 53; **35**: 299.

from sixteen to thirty years. During these years, no very significant changes have been discovered in the respect just indicated. I excluded also, not only in case of the whites but also among the other races, the record of every individual who had noticed particularly any diminution in his hearing acuity. Obviously those with defective hearing should not be included in any comparative measure of the hearing function, since they form a distinct functional group or species.

The average age of the whites was found to be 23 years and 5 months. About one third of them were older than 25 years, while one fifth only were younger than 20. The majority, therefore, of the Whites used here for comparative purposes were between the ages of twenty and twenty-five years—men and women in the younger years of adulthood, at a period of life most favorable for accurate testing.

On the average, the results show a slight superiority of the left over the right ear, the average for the latter being 33,087 D. V., as against 32,285 D. V. for the former. This is in accord with the observations of Preyer and Fechner, who observe that the left ear is superior to the right in all its functions, due, they believe, to the fact that human beings are left brained. In the case of my own measurements, however, much may have had to do with the order of testing the two ears. During these tests, the right ear was almost invariably first tested, so that a mental element arising from practise may have been responsible for the superiority of the left ear. If instead of the average we take the median as the measure, the difference in result is not changed.

The reliability of the averages, which may be directly computed from the S. D. given in Table I., is such as to indicate that the chances are about ten to one that the true average will not vary from the one given by more than 200 vibrations, which in reality, is within the range of instrumental accuracy; that is, the true average will not be as high as 32,500 vibrations to the second or as low as 32,000.

Reference to tables II. and III. will show that the distributions are fairly normal. Exclusion of the records of all individuals who had experienced some hearing defect has served to eliminate the skewness which might otherwise be looked for at the lower end of the curve.

Indians

So far as I am aware, no study of the hearing of our American Indian has ever been undertaken. There are, to be sure, in the literature relating to this interesting race of people, some general ob-

servations of a wholly unscientific character which, for the most part, attribute to the savage of the American forest and plains, a remarkable sensory acuity. The works, for example, of James Fenimore Cooper, contain statement after statement, all purporting that the Indian has ears that hear so keenly that he is able to detect sounds in the forest that are wholly inaudible to the ears of a white man most favorably gifted in this respect. And, indeed, whether from the popular literature relating to Indians, or from a preconceived notion that a savage ought to be superior to civilized peoples in sensory acuity, the opinion generally prevails that the ears of the Indians are very much keener than are those of the Whites. No doubt much of this conception arises from the belief in what is commonly known as the doctrine of compensation. According to this view, if one sense or mental function is lacking, in any respect, the others are the keener to compensate for the loss. Moreover, based on the olfactory sense of the dog, the visual acuity of the hawk and the superior audition of certain of the felines, there has arisen the belief that the senses degenerate under the influences of civilization and higher culture.

The figures relating to the upper limit of the hearing of the various Indian tribes represented at the Model Indian School at the Exposition, are given in tables I., II., III. and IV.[6] The hearing of 71 Indians included in this group was taken; 14 full-blooded males and 13 of mixed blood; 4 full-blooded females and 40 of mixed blood. Of this number, 8 were younger than sixteen years so that data relating to them are not included in the general average. Only 6 individuals of the group were older than 25 years (See Table IV.) while but 12 of the 63 were older than 20 years. In other words, 81 per cent. of all the Indians examined were between 16 and 20 years old. The average age of the entire group is only 19 years and 2 months, while that of the Whites with whom they are compared is 23 years and 5 months. It is therefore evident that, if the upper range of hearing progressively decreases from earliest childhood, the Indians are favored in the comparison with the Whites. For the right ear, the tone marking the upper threshold of hearing of Indians is on the average 31,975 double vibrations to the second, with an average deviation amounting to 2,190 vibrations. The average for Whites for the same ear was 310 double vibrations higher. On purely statistical grounds[7] one would be justified in

[6] For general remarks relating to these Indians more specifically consult page 4.

[7] In making these computations, the formulæ commonly used in statistical data for measuring the reliability of a difference were employed. See Thorndike, "Mental and Social Measurements," 1904, p. 139, et seq.

inferring that the chances are almost two to one (exactly 1.91 to 1) that an actual difference exists between the upper limit of hearing of Whites and Indians respectively. The difference however is too small, considering that neither group is very numerous, to point strongly in the direction of a real difference. The age factor, moreover, is of some importance in affecting the data as may be seen when we take the records of those individuals only whose ages run from 16 to 20 years—the figures which encompassed the largest number of the Indians examined. We have, then, 51 Indians and 43 Whites. When this reduced group is taken, the average upper threshold value for Indians, in case of the right ear, is found to differ only slightly from that found for the whole group, namely, 32,080 vibrations. On the contrary, the average for the Whites, when thus limited to those between 16 and 20 years, is increased to 33,587 vibrations. On statistical grounds, therefore, the chances are 10 to 1 that the upper limit of hearing for Whites is 1,000 vibrations in excess of that for Indians, and 400 to 1 that a real difference exists between the upper limit of hearing of the two peoples, on the average. Turning our attention now to the left ear, the difference between the two peoples seems still greater. The left ear too probably gives a figure which more nearly represents the actual state of the organs on account of the practise which the individual had in the experiment, as pointed out above. For this ear, on the average, the Whites hear tones of a pitch amounting to 1,500 vibrations higher than do Indians. Moreover, the probability of a real difference between the two peoples is at least 500 to 1, which, indeed, is extremely high. Although the conclusion is not so positive as though a larger number of each group had been measured, yet the data point in that direction to a degree amounting almost to certainty. Not only do Whites hear tones, which are more acute, on the average, than do Indians, but a glance at the distributions found in tables II. and III. will show that the entire curve for Indians for both ears extends lower than that of Whites. The amount of variability likewise appears to be greater in the case of Indians. As regards the right ear, one white woman only heard a tone higher than any of the Indians, and for the left ear, the best Indian did as well as any White.

Again looking at tables II. and III. from another angle, it may be observed that the relative inferiority of the range of Indians' hearing is not due to a few extreme records, which would have a tendency to distort the figure representing the average. As regards the right ear, the data presented show that 44 out of 67, or 66 per cent. of the records of Indians fall below the average for

Whites, and in case of the left ear, 41 of the 65 records or 63 per cent.

Cocopa Indians—The Seri.—Of this tribe, we were able to make

COCOPA INDIANS

Highest Audible Tone

Name	Age	Right Ear	Left Ear
Hi	6	32,180 D. V.	30,270 D. V.
Skik	14	31,170 "	31,170 "
Mert	14	33,060 "	34,000 "
El Puck	15	31,170 "	31,170 "
Jack	17	33,060 "	31,170 "
John Roy	18	31,170 "	33,060 "
Joe	20	34,000 "	34,000 "
Jerry	40	31,170 "	29,508 "
Pablo	56	(18,000 ")	(21,420 ")
Tom	70	(16,000 ")	
Average		32,123 "	31,794 "
S. D.		977 "	1,566 "

measurements of ten males only. On account of the variations in age, too, the data are not very suitable for comparative purposes. The youngest member of the group was a lad of six years, while the oldest had passed the age of three score and ten. All of the essential data with reference to these people are presented in detail in the table above. The records of the two oldest men have been enclosed in parentheses to indicate that they have not been included in casting up the averages for the whole. Both Tom and Jerry heard even ordinary conversation with difficulty, so that obviously their range of hearing could not be taken as normal to the group. Excluding, then, these two records, it is seen that the average upper limit of audibility of Cocopa Indians for the right and left ears respectively is 32,123 and 31,794 vibrations (double) to the second, figures which do not differ materially from the averages obtained from the more intelligent Indians at the U. S. Government schools. However, considering that only one of the eight individuals whose hearing records contribute to the average was older than 20, it is probable that the range of hearing of Cocopas in the long run would be found to be less than that of the more intelligent Indians; but even so, the difference would likely be psychological rather than organic.

Compared with the upper limit of hearing of Whites, the Cocopas fall significantly lower. Not only is this true as regards the average result, but age for age, the individual records are found to fall decidedly below the medians for Whites, as may be seen by comparing the distributions of the groups exhibited in tables II. and

III. In case of the upper limit of hearing for the right ear, 6 of the 10 Cocopas stand lower than the median record for Whites and 6 of the 9 in case of the left ear.

Vancouver Indians—Kwaguitls and Nutkens.—Of Vancouver Indians, we tested five males and two females, belonging to two local tribes.

VANCOUVER INDIANS—KWAGUITLS AND NUTKENS

Highest Audible Tone

Name	Age	Sex	Tribe	Right Ear	Left Ear
Bob	40	Male	Kwaguitl	26,264 D. V.	26,854 D. V.
Charley	28	"	"	28,766 "	28,766 "
Jasper	27	"	Nutken	28,048 "	26,854 "
Curley	21	"	"	26,264 "	28,048 "
Atleo	64	"	"	30,270 "	28,766 "
Ellen	35	Female	"	29,508 "	26,854 "
Anna	30	"	"	28,766 "	26,854 "
Average				28,269 "	27,571 "
S. D.				1,413 "	852 "

With the exception of Atleo—whose hearing record is the best of the group—these Indians were all in the prime of life. They are Indians, moreover, who have only to a small degree been influenced by contact with Whites, inasmuch as their homes are far removed from those parts where civilization has made its march. So far as the data will permit of generalization, therefore, I believe these peoples to be fairly representative of the more intelligent Indian of North America, before his organism has become modified by its adjustment to the social conditions and habits of the invading Caucasians.

In the case of both ears, the degree of variability among the records is fairly small. By reference to the table above, it is seen that the range of all the cases is encompassed by less than 4,000 vibrations to the second; or that part of the musical scale lying between gis^6 and bis^6, *i. e.*, within the range of less than two whole tones. The records for the left ear (exhibited in Table III.) are lower, as a whole, but the difference between the highest and lowest record is still smaller, being only about a semi-tone (1912 D. V.).

It is, however, worthy of note that not a single record of the Vancouver Indians is as high as the average for Whites. In fact, the highest Vancouver Indian record for the right ear is 1,000 D. V. lower than the mean for Whites, while the highest for the left ear is 3,500 D. V. lower. The numbers are too small to apply statistical methods with satisfaction, but there certainly is no question of the evident tendency toward the inferiority of these Indians in hear-

ing range, as compared with Whites. The records of the two women are poorer than those of any of the men, but additional representatives of the women might tend to reverse this result.

Patagonian Indians—The Tehuelche.—We were able to examine only four men of this tribe, the data concerning whom are given below in detail. These Indians represent a grade of culture slightly lower than that of the Vancouvers just considered; a tent-living instead of a house-dwelling people, a nomadic instead of a home-building folk.

PATAGONIAN INDIANS—THE TEHUELCHE

Highest Audible Tone

Name	Age	Right Ear	Left Ear
Cosimero	24	26,854 D. V.	26,264 D. V.
Canjo	35	28,766 "	27,444 "
Senchel	55	Hearing very defective. About 10,000 D. V. for both ears. An acuity defect.	
Boni Farci	18	35,100 D. V.	32,180 D. V.
Average		30,240 "	28,630 "
S. D.		3,551 "	2,592 "

Only three records were included in the average. The number examined is too small to draw any general conclusions. However, with the exception of Boni Farci, the upper limit of hearing of all was found very much inferior to that of the average for Whites. I leave the data without further comment.

Indians as a Whole.—From the foregoing, it is evident that whether taken tribe by tribe or as a whole, on the average as well as individually, the experimental results indicate that Indians do not possess as great a range of hearing as do Whites. If, indeed, we lump the records of all the Indians irrespectively, those who have had the cultural advantages of the Whites—the tribes represented in the group taken from the Indian School—with the smaller groups represented by Indians closer to nature, we find that for the right ear, 60 of a total of 83, or 73 per cent. of the individuals rank below the average for Whites, and 64 of 82 Indians, or 77 per cent. stand lower than the average of Whites as regards the left ear. It is worthy of note too that the better records were made by those Indians who had attended, more or less, the Government Indian Schools. It was my impression also, formed at the time of making the measurements, that the better records were made by those individuals who were, all around, more intelligent and alert. Unfortunately, it had not occurred to me to make record of the degree of intelligence of each person when tested, although it might be nothing more than a personal opinion based upon observation only.

Roughly, this could easily have been done with a fair degree of accuracy, since I was associated with and saw at work each person for the better part of an hour. Had I made such an observation, it would have enabled me to determine in a loose way, at least, how far the differences in the upper limit of hearing between Whites and Indians are psychological and to what extent organic in character. A little further on, we shall have occasion to revert to this subject again.

Filipinos.—In all, 97 Filipinos were tested for their upper threshold of hearing. The data for four, however, were so palpably in error, that the records were rejected. We thus have 93 records which form the basis for the following study. So far as I am aware, no statement has ever been made with reference to the hearing of any of the Filipino people, in any of its aspects. It is doubtful, too, whether so good an opportunity for testing these peoples, and under circumstances so favorable, will soon be found again. If taken in the Islands, it would be no easy matter to collect into a laboratory, for testing, as many as a hundred individuals, representing, as did these, almost every section of the Philippine Archipelago.[8] We feel especially gratified with the results obtained on the Filipino peoples. For the opportunity of making measurements of the Filipinos, I am under obligations to Major Haskell, U. S. A., under whose orders the men came to the laboratory for the testing and without which orders it is doubtful whether the tests could have been made at all. Obligations are also due to Dr. Wilson, of the Philadelphia Museum, who, in the capacity of Director of the Philippine Exhibit, used his influence in our behalf to the extent of recommending that we be given permission to make the measurements.

The men were brought to the laboratories, four at a time, this number being tested in the forenoon and the same number immediately after dinner. It may here be stated that the hearing examinations were but two of a great number made on each individual. The men were ignorant as to the object of the measurements nor was there a hint given of their purpose. Notwithstanding, they approached the tests with a great deal of interest and zeal, and seemed eager to compare their several records with those of their fellows. None of them suspected that there might be such a thing as a racial difference inasmuch as they referred to my record as one, in all respects, comparable with one of theirs.

The men were taken into the sound-room, one at a time, and the test conducted with as great dispatch as possible in order to avoid the flagging of interest and the onset of fatigue.

[8] See page 6 for a more detailed description of these peoples.

It is seen, from the age distributions found in Table IV. (See p. 34) that 4 men were younger than 18 years and 5 older than 25. The oldest of the group was but 30. Were one to select the individuals deliberately with the test of the upper threshold of hearing in view, it is difficult to see how a more favorable lot could have been secured. The mean age was 21 years and 1 month.

Turning now to tables I., II. and III., it is seen that the figure representing the upper threshold of hearing of Filipinos for the right ear was found to be 29,916 vibrations to the second on the average, and for the left ear 29,886 vibrations. The small degree of variability found in the group is at once striking. The average deviation is very much smaller than that for either Whites or Indians (See Table I.). So little variability, no doubt, may be accounted for by the fact that the variation in age is likewise small and, moreover, it may be noted that in mental alertness and general intelligence, these individuals were more nearly on a par than those of any other group measured, and, consequently, all mental factors concerned in the tests would become more largely equalized.

When compared with Whites, the upper limit of hearing of the Filipinos is decidedly lower, not only on the average, but also as regards the general distribution of the individual cases; a fact which stands out in the general distributions found in tables II. and III. The figures show that Whites on the average have an upper limit of hearing higher by 2,369 vibrations for the right ear and by 2,301 for the left. On the basis of mathematical probability, the chances are such as to amount almost to an absolute certainty (10,000 to 1) that, even were the numbers infinitely increased, the upper limit of Filipinos would, on the average, be lower than that of Whites. Indeed, the chances are about 4 to 1 (3.9 to 1) that the difference between the upper limit of hearing of Whites and Filipinos amounts to at least 2,000 vibrations. And, inasmuch as the number measured is sufficiently large to render the data susceptible to fairly accurate statistical treatment, the reliability of these figures may be accepted with a certain degree of confidence.

Something of the standing of the upper limit of hearing of the Filipinos as a whole may be inferred from the distribution of the records as found in tables II. and III. Not only the mode, but the distribution as a whole is found to fall distinctly below that for Whites. Take, for example, the records of the right ear. But 19 of the whole number of 93 (about 20 per cent.) are as high as the median record for Whites; for the left ear, only one Filipino record is as good as the median for Whites.

In the data just presented, were included the records of 13

Filipino students attending American colleges and universities, who were temporarily connected with the Exposition and whom we tested as they chanced to stroll into the laboratories. These records afford an opportunity for testing to what extent the factor of intelligence was instrumental in effecting differences found to exist between the upper limit of Filipinos and Whites. In mentality, I take it, these Filipino students were on a par with the freshmen and sophomores in our American colleges and universities. They ranked, moreover, in point of intelligence at least equal to the Whites with whom the Filipinos are compared above, inasmuch as the Whites were for the most part artizans and tradespeople, with a few who had completed college courses. Below I give the individual records of these Filipino students, both for the right and left ears. Also I give the averages of the thirteen records and the variability.

FILIPINO STUDENTS—MOSTLY TAGALOGS

Highest Audible Tone

Right Ear	Left Ear		Right Ear	Left Ear
31,170 D. V.	33,060 D. V.		32,180 D. V.	32,180 D. V.
34,000 "	31,170 "		32,180 "	32,180 "
31,170 "	31,170 "		35,100 "	33,060 "
32,180 "	32,180 "		30,270 "	28,766 "
29,508 "	28,766 "		33,060 "	33,060 "
33,060 "	30,270 "	Average	31,878 "	31,157 "
30,270 "	30,270 "	A. D.	1,323 "	1,361 "
30,270 "	28,766 "			

Even these intelligent and educated Filipinos, it is seen, have an upper range of hearing distinctly lower, on the average, than do Whites; the difference for the right and left ears respectively being 407 and 1,930 vibrations. Were the numbers of these intelligent Filipinos larger, it would be interesting to note what the probabilities of a real difference are between their upper limit and that of Whites. The data would incline one to believe that they would amount to practically a certainty. It requires to be noted, moreover, that with one exception, the records of the Filipino students were among the best of the Filipinos tested, so that there can be no doubt but that the psychological factor is significant in accounting for some of the differences discovered between Filipinos and Whites, though, to be sure, by no means all.

Army officers, who had done service for some time, in the Philippines, and some teachers who had spent two or three years in the Islands, with whom I conversed, without exception informed me that they, too, had experienced defective hearing in the Philippines. But they attributed this abnormality to the action of the quinine,

which they found it necessary to take in large quantities, on account of the prevalence of fevers. Since the natives are immune to malaria and other tropical maladies, and do not use quinine or other drugs with similar medicinal properties, the explanation just noted could not account for the defective hearing of the Filipinos, which, as will hereafter be pointed out, extends not only to a diminution of the range but to an actual lack of acuity as well. It would be interesting to know whether this is common to all dwellers within tropics, inasmuch as the results are in accord with the data collected from the inhabitants of the Torres Straits.*

Ainu.—Excepting the Vancouver Indians, the Ainu rank lowest as regards the upper limit of hearing of any of the peoples I examined. Owing to the fewness of the numbers, it is impossible to do more than present the results with a statement of their general tendency, and perhaps this can best be seen from the comparative tables II. and III. It may be noted that all of the Ainu records fall lower than the average for Whites for both the right and left ears. The general tendency seems to indicate an upper limit slightly lower even than that of Filipinos.

THE AINU

Highest Audible Tone

Name	Age	Sex	Right Ear	Left Ear
Yaso Osawa	23	Male	31,170 D. V.	31,170 D. V.
Kutorge Hiramura	38	"	30,270 "	24,754 "
Santukuno Hiramura	53	"	25,212 "	26,264 "
Goro Bete	28	"	29,508 "	32,180 "
Sangea Hiramura	56	"	Less than 10,000 D. V. (both ears). Record not included in the average.	
Ume Osagwa	19	Female	28,048 D. V.	33,060 D. V.
Shutratek Hiramura	33	"	25,212 "	26,264 "
Kin Hiramura	6	"	30,270 "	30,270 "
Average			28,846 "	29,529 "
A. D.			1,666 "	2,946 "

Much of the auditory inferiority of the Ainu is undoubtedly to be accounted for on purely psychological grounds. They seemed an excessively stupid people, ranking next to the lowest of all the primitive peoples collected on the Exposition grounds. Their minds seemed unresponsive and lethargic. They apprehended meanings poorly. Things once apprehended, moreover, held their attention for a moment only when they seemed immediately to relapse into a state of mental indifference. I never could feel quite certain that they were hearing even when they said they were, inasmuch as in the region of the threshold values the number of false statements was exceedingly large.

* See Report Cambridge Anthropol. Exp., Vol. II.

The Ainu have been little studied and little is known of them. So far as I am aware, no scientific measurements of them have ever before been made, so it is quite unfortunate that more of the race were not available for study. It is a race, too, which, according to travelers and missionaries, is fast dying out; hence, in the near future, will no longer be open to scientific observation.

The Pigmies—Batwa, Batsuba and Cheri Cheri.—Of the so-called Pigmies proper, there were at the Exposition only six representatives. I present hearing records of the entire number.

The Pigmies—Batwa, Batsuba and Cheri Cheri

Highest Audible Tone

Name	Age	Tribe	Right Ear	Left Ear
Shamba	30	Batwa	31,170 D. V.	31,170 D. V.
Malinga	16	"	37,560 "	37,560 "
Bushaba	13	"	32,180 "	39,220 "
Latuna	15	Batsuba	35,100 "	35,100 "
Otabenga	17	Cheri Cheri	30,270 "	31,170 "
Lumme	17	" "	33,060 "	30,270 "
Average			33,323 "	34,081 "
A. D.			2,071 "	3,212 "

The records of the Pigmies are all high. Were the same relative distribution to continue for a hundred Pigmy hearing records, they would be found to possess an upper range of audition superior to that of any other people, including Whites. The general distribution of their results stands higher than that for Whites. (See tables II. and III.) Only one white male was found to possess a range of hearing higher than that of any Pigmy.

How shall we account for this manifest superiority of the Pigmy's hearing? Certainly not on the basis of a superior mental attitude toward the tests, since the Pigmy ranks low in the mental scale—only slightly higher than the Ainu whom we have just considered. Moreover, their interest in the test can not be said to have been especially keen. It was certainly by no means the equal of the Filipinos whose upper limit was found to be especially low. The question of age was a factor, no doubt, since the Pigmies were all boys, but even this does not account for all the difference found. Perchance, something of a relation may exist between a high degree of sensitivity and extreme motility. The Pigmy is a motor individual. Like his next of kin, the negro, in his native haunts, he is perpetually on the move. His reactions to incoming stimuli likewise are direct and excessively overt. Other than this, there is certainly nothing in the Pigmy's environment or mode of living which should tend to develop and cultivate any peculiar aptitude in the way of sensory acuity, with which he seems naturally to be gifted.

CHAPTER V

The Upper Limit of Hearing as Affected by Age and Sex

From the data I was able to collect at St. Louis and some gathered subsequently from children in the public schools, it was possible to select material which will throw some additional light upon the relation that obtains between range of hearing and age and sex. As regards Whites alone, the data represents tests on 385 individuals; 209 males and 176 females, ranging in age from 5 to 65 years.

By consulting the tables and charts which follow (See tables V. to XII.) it will be observed that the records of the individuals have been distributed into *four-year* groups, the first group representing the upper limit of hearing of children between 5 and 8 years inclusively; the second group 9 to 12 years, and so on. Beyond 49 years, the numbers tested were so few that the four-year groupings were dropped and the records lumped. Such a procedure, too, is justifiable on other grounds. With the approach of senescence is met a decrease of sensitivity, in general, in consequence of which many of the data would bear record of a decline in general sensibility rather than a diminution only in the one particular function of hearing piercing tones.

In Table V. the data are so arranged as to contribute information toward the significance of age in influencing the upper limit of

TABLE V

Highest Audible Tone, According to Age

Ages	No. of Cases	White Males and Females		White Males and Females	
		Right Ear Average	Left Ear. Average	Right Ear. Median	Left Ear Median
5–8	41	34,826	34,525	34,000	35,100
9–12	32	34,614	34,939	35,100	34,200
13–16	54	34,419	34,234	34,000	34,000
17–20	40	32,466	32,415	32,480	32,200
21–24	48	33,491	33,025	32,480	33,800
25–28	53	31,557	32,300	32,180	32,200
29–32	31	31,464	32,000	32,180	31,200
33–36	17	28,816	29,046	28,900	29,000
37–40	27	27,512	26,064	26,864	28,100
41–44	12	27,963	29,994	29,608	27,600
45–48	20	27,282	27,741	26,864	27,500
49+	12	28,020	26,188	28,048	25,212

TABLE VI

HIGHEST AUDIBLE TONE, ACCORDING TO SEX

Ages	No. of Cases	White Males		No. of Cases	White Females	
		Right Ear. Average Vibration Frequency	Left Ear. Average Vibration Frequency		Right Ear. Average Vibration Frequency	Left Ear. Average Vibration Frequency
5- 8	18	35,180	34,926	23	34,535	34,211
9-12	17	34,500	34,740	15	34,861	35,062
13-16	31	34,207	33,893	23	34,671	34,713
17-20	24	32,103	31,546	16	32,991	32,849
21-24	26	33,069	31,358	22	33,565	33,714
25-28	19	30,834	31,480	34	31,048	32,059
29-32	22	31,105	31,761	9	32,740	32,168
33-36	10	29,316	30,005	7	28,101	28,161
37-40	15	24,142	26,498	12	25,152	27,255
41-44	6	25,316	27,064	6	30,748	31,035
45-48	11	27,435	27,894	9	27,319	27,571
49+	10	25,424	26,244	2	25,224	25,826

hearing. In this table the sexes have not been segregated. The table is made to show differences between different periods of life, both in terms of the average of the individual records of each age group and in terms of the median or middle record. The latter gives the data in such terms that the influence of pathological, or functional, disturbances of hearing is largely eliminated. That is, extreme records which have a tendency to skew the average lose their unwarranted weight. From this table, as well as from others which will follow, something, also, may be inferred as to the relative range of sensitivity of the two ears.

In Table VI. the data are arranged so as to exhibit any sex differences that might be found for the various age groups. Neither in this table nor Table V. has there been worked out, however, any measure of variability, inasmuch as the character of the distributions may be seen in tables VII. to XII.

Tables VII. to XII. present the original data in such form that they may be worked over by anyone who cares to review the question; and, indeed, they show more convincingly than any series of figures representing averages, modes or medians could possibly do, the tendencies of the several groups measured. Perhaps a word of explanation is necessary to an understanding and interpretation of these tables. Taking, for example, Table VII. In the column to the left are given the lengths of the whistle cavity employed in the various hearing measurements, and in the column to the right the corresponding vibration frequencies (double) of the resulting tones. At the head of the several columns are indicated the different age groups; "5–8" indicating that the data in the column beneath are those secured from boys and girls without distinction of sex; and so

on for the remaining columns. Again, under the "5–8" caption, the "4" indicates that four individuals were measured in which the whistle cavity had a length of 1.4 mm. or the tone possessed a vibration frequency of 39,220 D. V. (double vibrations), and so on, the "12" indicating that the upper limit of twelve children was marked by a tone of 35,100 D. V.

Extended interpretation and discussion of the data contained in tables V. to XII. are uncalled for in connection with the problem of racial differences, of which this paper particularly treats. A few words, however, are perhaps not out of place.

It will be observed that the number of individual measurements recorded, especially as regards the younger years, is sufficient to make the conclusions fairly definite. From tables V., VII. and XII. it stands out fairly clear that there is practically no shortening in the range of hearing before the age of sixteen years, but that after this age the upper limit falls slowly, having sunk about three-

TABLE VII

UPPER LIMIT OF HEARING

Males and Females (White)—Right Ear

Whistle Length mm	Ages in Years 5–8	9–12	13–16	17–20	21–24	25–29	30–39	40–49	50–59	60–69	70–79	80 and over	Vibrations (Double) Per Sec.
1.2													42,960
1.3			1										40,840
1.4	4	3	3		2	1							39,220
1.5	3	3	6		3	2	1						37,560
1.6	4	3	4	3	6	2	1			1			36,380
1.7	12	7	5	8	5	3			1				35,100
1.8	4	6	15	5	6	5	4			1	1		34,000
1.9	7	2	7	5	7	8	2						33,080
2.0	6	4	8	10	5	8	7	2	1		1		32,180
2.1	1	3	4	3	6	6	6	3	2	2	2	1	31,170
2.2		1	1	3	4	3	3	2	4	1	2	1	30,270
2.3				2		3	2		2		1	1	29,508
2.4				2	1	1	3	2	2	1		1	28,766
2.5				2	2	5		2	2		3		28,048
2.6									1				27,448
2.7						2		3	2		1	1	26,854
2.8								2	1	1	1		26,264
2.9						1	1		2				25,734
3.0						2	1		1	2	2	2	25,212
3.1								1	2		1		24,754
3.2									1		2		24,196
3.4						1				2	2	2	23,080
3.6									1		1	1	22,217
3.8									1	1		1	20,973
4.0									1				18,486
Average D. V.	34,826	34,614	34,418	32,464	32,491	31,557	31,444	28,816	27,819	27,563	27,282	26,000	

TABLE VIII

Upper Limit of Hearing

Males and Females (White)—Left Ear

Whistle Length mm.	Ages in Years 5–8	9–12	13–16	17–20	21–24	25–28	29–32	33–36	37–40	41–44	45–48	49 and Over	Vibration Frequency D. V.
1.2					1								42,960
1.3		1				1							40,840
1.4	2	3	1	1									39,220
1.5	5	4	8		2	2							37,560
1.6	3	3	4	1	1		1						36,360
1.7	7	6	6	3	5	2			1	1	1		35,100
1.8	5	5	14	4	2	1	2						34,000
1.9	8	4	8	3	2	4	3		1	1			33,060
2.0	9	2	4	3	1	2	4	1	1	2	1		32,180
2.1	1	2	4	3	5	3	4	1	2		2		31,170
2.2		2	2	2	1	2		3			1	1	30,270
2.3			1		2	1	2	1	1	2		1	29,508
2.4				2	1			1			2	3	28,766
2.5				1	1	1	1	2	1		1		28,048
2.6					1			1	1	2	1		27,448
2.7								1			5	1	26,854
2.8						1			1	1	1		26,264
2.9				1		1		1	1				25,724
3.0									1			1	25,212
3.1									1	1			24,754
3.2									1	1	2		24,196
3.4											1	1	23,020
3.6									1		1	1	22,217
3.8													20,973
4.0									2			1	18,496
Average D. V.	34,525	34,939	34,224	32,415	33,025	32,390	32,000	29,046	25,054	29,994	27,741	28,188	

fourths of an octave on the average by the forty-ninth year. The data giving the median record for each age group disclose the same facts, so that it seems to matter not whether we speak in terms of the average or the median (See tables V. to XII.).

It will be remembered that Alderton, Blake, Galton, Zwaardemaker, Caperius, Myers[1] and others found that by the age of 12 to 13 years, the upper limit of hearing already exhibits considerable shortening. My data necessitate a conclusion quite at variance with that of these earlier experimenters. Nor can I suggest an explanation for this lack of harmony in our experimental results.

A mathematical statement of the probability of a difference in the range of hearing on the average for years of life beyond seventeen, is wholly superfluous in view of the distributions of individual records exhibited in tables VII. to XII. which makes this conclusion absolutely certain. But to explain this shortening in range with

[1] See discussions under Chapter II., page 19, et seq.

increasing years is a more serious question. Whether it is but a symptom of a general insensitivity of the organism as the individual ages or only an atrophying of certain tissues through disuse, which were of service to man in a lower stage of his culture, or whether it may be due to other factors, are questions which await experimental determination. In view of the relative inferiority of the extent of hearing range among primitive peoples, the former of the two suggested explanations perhaps seems the more plausible.

TABLE IX

UPPER LIMIT OF HEARING

Males—Right Ear

Whistle Length mm.	Ages in Years 5–8	9–12	13–16	17–20	21–24	25–28	29–32	33–36	37–40	41–44	45–48	49 and Over	Vibration Frequency D. V.
1.2													42,960
1.3													40,840
1.4	2	1	2		1								39,220
1.5	1	2	4		2	1	1						37,560
1.6	2	2	1		3	1							36,360
1.7	6	4	4	4	3	1							35,100
1.8	3	2	8	2	3		3						34,000
1.9	4	1	4	4	4	3	1						33,060
2.0		3	3	6	2	2	4	2					32,180
2.1		1	4	1	2	3	4	2			2	1	31,170
2.2		1		3	2	2	3	2	2	1	1	1	30,270
2.3			1	1			2		2		1		29,503
2.4				2	1		2		2			1	28,766
2.5				1	2	3		1	2		2		28,048
2.6									1				27,448
2.7						1		1	2			1	26,854
2.8								1	1	1			26,264
2.9							1		1				25,724
3.0						1	1			2	2	2	25,212
3.1					1			1	2		1		24,754
3.2											2		24,196
3.4						1				1		2	23,020
3.6										1		1	22,217
3.8													20,973
4.0												1	18,496
Average D. V.	35,198	34,500	34,207	32,103	33,069	30,834	31,105	29,316	24,142	25,366	27,435	25,424	

As to a difference in sensitivity between the two ears, taking the results as a whole, all ages together, nothing like a significant difference stands out in the tables (Table V.). As to a sex difference, it would appear from Table VI. that woman's range of hearing extends slightly higher than man's; the difference is however for each age-group too small to possess any high reliability.

TABLE X

UPPER LIMIT OF HEARING

Males (White)—Left Ear

Whistle Length mm.	Ages in Years 5–8	9–12	13–16	17–20	21–24	25–28	29–32	33–36	37–40	41–44	45–48	49 and over	Vibration Frequency D. V.
1.2													42,960
1.3													40,840
1.4	2	1											39,220
1.5	1	2	4										37,560
1.6	2	1	2										36,360
1.7	4	5	5	1	1	1							35,100
1.8	4	4	7			1							34,000
1.9	3	2	5	2	1	2	2						33,060
2.0	2	1	3	1	1	1	2						32,180
2.1		1	2	1	2		2	1			2		31,170
2.2			2	1				3				1	30,270
2.3			1				1			1			29,508
2.4				2	1						2	3	28,766
2.5					1			1	1		1		28,048
2.6									1	2			27,448
2.7											3	1	26,854
2.8										1	1		26,264
2.9									1				25,724
3.0												1	25,212
3.1									1	1			24,754
3.2											1		24,196
3.4												1	23,020
3.6													22,217
3.8													20,973
4.0												1	18,496
Average D. V.	34,936	34,740	33,893	31,546	31,358	31,480	31,761	30,005	26,498	27,084	27,894	26,244	

SUMMARY AND CONCLUSION

Placed in the order of superiority, beginning with the people whose upper limit was found to be the highest, the peoples arrange themselves in the following order:

Right Ear

1. Pigmies.
2. Whites.
3. Cocopa Indians.
4. Indians from the Schools.
5. Patagonian Indians.
6. Filipinos.
7. Ainu.
8. Vancouver Indians.

Left Ear

1. Pigmies.
2. Whites.
3. Cocopa Indians.
4. Indians from the Schools.
5. Filipinos.
6. Ainu.
7. Patagonians.
8. Vancouver Indians.

There is a slight difference in relative order for the two ears, respectively, which may be, and probably is, due to the fact that

TABLE XI

Upper Limit of Hearing

Females (White)—Right Ear

Whistle Length mm	Age in Years 7–8	9–11	12–16	17–20	21–25	26–30	31–35	36–40	41–45	46–50	51–55	56 and Older	Vibration Frequency D V
1.2													42,960
1.3			1										40,840
1.4	2	2	1		1	1							39,220
1.5	2	1	2		1	1							37,560
1.6	2	1	3	3	3	1	1			1			36,360
1.7	6	3	1	1	2	2			1				35,100
1.8	1	4	7	3	3	5	1			1	1		34,000
1.9	3	1	3	1	3	5	1						33,080
2.0	6	1	5	4	3	6	3		1		1		32,140
2.1	1	2		2	4	3	2	1	2	2			31,170
2.2					2	1			2		1		30,270
2.3				1		3						1	29,504
2.4						1	1	2		1			28,766
2.5				1		2		1			1		28,044
2.6													27,448
2.7						1		2			1		26,854
2.8								1			1		26,264
2.9						1			1				25,724
3.0						1			1				25,212
3.1													24,754
3.2									1				24,196
3.4										1	2		23,020
3.6									1		1		22,217
3.8									1			1	20,973
4.0									1				18,496
Average D V	34,535	34,861	34,671	32,961	33,565	31,044	32,740	28,101	25,152	30,748	27,319	26,240	

the numbers making up some of the groups were small. The larger groups, Whites, Indians (from schools), and Filipinos, on the other hand, retain the same order, for the two ears, unchanged. It is reasonably certain that Whites have a higher upper limit of hearing than do Indians and that Indians in turn have a wider range of tonal hearing than do Filipinos.

The data, therefore, bring out strikingly and justify a conclusion, amounting, practically, to a certainty that racial differences in hearing exist, at least so far as the upper limit of hearing goes, and that the more cultured people rank most favorably in this respect. So far as the data are comparable, too, my experimental conclusions with Filipinos are strictly in accord with those of Dr. Myers, on peoples of the same race. Dr. Myers's results are stated in terms of the cavity length of a small Hawksley-Galton Whistle and, consequently, his data can not be compared directly with my own, but Myers found that, for the most part, the Papuans whom

TABLE XII

UPPER LIMIT OF HEARING

Females (White)—Left Ear

Whistle Length mm.	Ages in Years: 6–8	9–12	13–16	17–20	21–24	25–28	29–32	33–36	37–40	41–44	45–48	49 and Over	Vibration Frequency D. V.
1.2					1								42,960
1.3		1				1							40,840
1.4	1	2	1	1									39,220
1.5	4	2	4		2	2							37,560
1.6	1	2	2	1	1		1						36,360
1.7	3	1	1	2	4	1			1	1	1		35,100
1.8	1	1	7	4	2		2						34,000
1.9	5	2	3	1	1	2	1		1	1			33,060
2.0	7	1	1	2		1	2	1	1	2	1		32,180
2.1	1	1	2	2	3	3	2		2				31,170
2.2		2		1	1	2					1		30,270
2.3					2	1	1	1	1	1		1	29,508
2.4								1					28,766
2.5				1		1	1	1					28,048
2.6					1			1			1		27,448
2.7								1			2		26,854
2.8						1			1				26,264
2.9				1		1		1					25,724
3.0									1				25,212
3.1													24,754
3.2									1	1	1		24,196
3.4											1		23,020
3.6									1		1	1	22,217
3.8													20,973
4.0									2				18,496
Average D. V.	34,211	35,083	34,713	32,849	33,714	32,059	32,168	28,161	27,255	31,035	27,571	25,862	

be examined, possessed a rather noticeably shorter range of hearing than did the peoples of Scotland in whose measurement he employed the same whistle.

Only two factors in explanation of the relative shortness of the range of hearing among primitive peoples have been suggested:

(*a*) Attention was called to the psychological factor concerned with the subject's attitude toward the test, or the subject's relative ability to attend to stimuli. This mental factor is undoubtedly a prominent one. It likewise has its motor aspects and relations. Those individuals who are relatively more alert, and whose range of motor responses likewise is greater, were, on the whole, found to possess a greater range of auditory sensitivity, than individuals less given to motility.

(*b*) The second factor, perhaps, is fundamentally the same as the first. It refers to climatic and geographical influences. It was suggested that, perchance, variations in upper limit of hearing may

be induced by factors arising from the different latitudes in which the individuals have been born and have grown up.

Each of the suggested factors just enumerated, however, awaits additional experimental evidence for verification. Unfortunately, I had neither the time nor facilities to enter further into the subject.

Lastly, it was found that age plays an important rôle in shortening the upper limit of hearing. While no perceptible shortening occurs before the sixteenth year, after this age the upper limit gradually drops, shortening almost an octave on the average during the next thirty years.

PART II

AUDITORY ACUITY

CHAPTER VI

Historical

Reference to the literature of auditory acuity from the point of view of this paper implies its consideration from two distinct aspects: (1) the relative acuity of some of the inferior races, and (2) a quantitative auditory measure. With reference to auditory tests on primitive peoples, the literature is indeed meager. If we exclude haphazard statements, and such as have been made by tourists without reference to the physical and psychological factors involved, the classic work of Dr. Charles Myers[1] on the Hearing of the Murray Islanders is about all of consequence that has found its way into print.

In the seven volumes which have been published relating to almost every phase of the life and environment of the natives of southern South America, P. Hyades[2] and J. Deniker encompass the problem of hearing within a single paragraph. The statement is so abbreviated that I quote it in full: "The Fuegians have the sense of hearing particularly developed owing to their conditions of life. Yet, by divers experiments with the watch, with the diapason, etc., we proved that the acuity and the range of hearing, among these people do not exceed that of Europeans especially gifted in this respect. It was observed also that noises such as are habitually disagreeable to us (Europeans), an explosion of a charge of powder, or the hissing of steam in escaping from a locomotive, do not by any means produce an unpleasant effect upon their ears." Such a statement as this, while indicating the direction of a tendency in the gross, does not give us much information on the question in point. The inference is, that the hearing is equal, at least, to the average among Whites. Nothing is said, moreover, as to the method pursued in testing, the individual differences observed, or of the number of persons tested.

[1] "Anthropological Expedition to Torres Straits," Vol. II.

[2] "Mission Scientifique du Cap Horn," Tom VII., p. 209. 1882–3.

In keeping with the statement just noted are such observations as that of Robertson[3] who remarks "As a result of very many observations of an unscientific kind, I could never discover that Kaffirs displayed any superiority to other races in their certainty of hearing." And that of Sir Francis Galton[4] who says "My own experience also, so far as it goes, with Hottentots, Damars, and some other wild races, went to show that their sense of discernment was not superior to that of white men." Giltschenko[5] also relates that the Osset, whom he examined, was found to hear the tick of the watch at no greater distance than other peoples. However, on the open plains and among the hills, the Osset understands spoken words and perceives significant sounds at extraordinary distances. But, as Dr. Myers critically remarks, extraordinary auditory acuity under such circumstances as that just related, where the stimuli possess a conscious significance, no more indicates superior hearing than does the superior ability to analyze clangs give evidence of a more efficient organic hearing sensitivity.

Myers quotes a personal communication from Stanley Gardener, in this connection, which illustrates what is patently true of all sense avenues, namely: that even very intense stimuli, if not significant or familiar, are usually unobserved. Gardener, while in the Maldive Islands, had an American clock hanging in his bungalow. He observed that the natives who had never seen a clock would often approach within two yards of the timepiece without noticing its tick, and even after he had called attention to the sound, they usually experienced considerable difficulty in localizing it. Gardener further relates that frequently he passed behind the natives on the sandy seashore, but that, invariably, they failed to distinguish his booted tread from that of the bare-footed savage.

More forcibly, perhaps, than any *a priori* statement of the matter, these observations emphasize the importance of carefully selected and well devised hearing tests for measuring primitive peoples, such as will not afford undue advantage to the intelligent over the inferior race with which it is compared. In other words, if a comparison of hearing is to be valid, the stimuli must so nearly as possible have the same psychological value for all the individuals in question. Unhappily, this condition is rarely fulfilled, not only as regards auditory stimuli, but those affecting other sense avenues as well. Whether suitable conditions for making comparisons obtained in the tests of Hyades and Deniker, the statement of their conclu-

[3] "Kaffirs of Hindu Kush," 1896, p. 174, quoted from Myers, *loc. cit.*

[4] "Inquiries into Human Faculty," London, 1883, p. 32.

[5] *Biol. Centralb.* **11**: 304–318. 1891.

sions leaves us in ignorance. Certainly such statements as those of Galton, Robertson, Gardener and Giltschenke lose all their value when weighed by psychological standards, simply because unequal psychological units of measure were employed in the comparisons. Myers more nearly meets the situation than any of the above in that he employed a metallic click, which possesses comparatively few associations, in some of his measurements, while in others, an ordinary noise produced by a pith ball falling upon an inelastic surface served as a stimulus. The last mentioned instrument consisted of a telescope tube mounted vertically; at the base of which extended a piece of felt, placed at an angle. The pith ball was allowed to drop through the tube, strike the felt below and rebound, falling noiselessly upon some velvet cloth stretched to catch it. The height from which the pith ball fell could be varied so as to change the intensity of the sounds. This device was found unserviceable, however, on account of surrounding noises. Myers and Rivers found considerable difficulty in their work of measuring the auditory acuity of the Murray Islanders, by reason of extraneous noises which so confused the subject under examination that he was frequently unable to tell when the stimulus was present and when not; that is, whether he heard the appropriate sound or not. Later, a Politzer Hörmesser was tried but with almost as little success, though a certain number of measurements were made with the instrument. But in by far the greater number of Myers's tests, use was made of an ordinary stop watch, the acuity of the native being recorded by the relative distance at which he and one of the experimenters could hear the tick. In each test, one of the experimenters stood beside the subject and also listened for the tick. It was thus observed whether or not he heard the tone at a greater distance than did the native; the distance at which the watch or the Politzer acuometer was audible to the experimenter always being the denominator of a fraction standing for the acuity of the native tested. Thirty-five natives were tested for hearing. Although the tests, as has just been indicated, were extremely rough, they served to show that Papuans, on the whole, do not hear as well as do Europeans, though some of the individual Papuans, indeed, heard better than did either Myers or Rivers. On their return to England, Myers compared his own hearing and that of Rivers with the hearing of other Europeans and these comparisons seemed further to confirm the relative inferiority of the auditory acuity of the Murray Islanders.

From the second point of view of my measurements of hearing, the literature is voluminous. Anything like a comprehensive review of all of its phases would, therefore, at once carry us entirely too

far afield. Indeed, it would be a bootless task, by reason of the diversity of methods employed and devices used, which it would be wholly impossible to place into any scale of equivalents.

Very considerable work has been done on the continent of Europe in the way of establishing quantitative auditory measures. Something in the same direction has been accomplished in the United States, and Lord Rayleigh, in England, has pretty thoroughly broken the ground in the way of making it possible to determine the energy proceeding from certain sonorous sources. I shall not, at this time, attempt to review the merits of the various devices and instruments that have been put forward for testing auditory acuity. Few of these should concern us in connection with a study of a quantitative measure of hearing, inasmuch as they are at best only semi-quantitative in character. The mere mention of a few such as the following will suffice to illustrate the point in question: The Seashore audiometer;[6] Bryant's and Bentley's[7] phonograph audiometer; the audiometer of De Graffe;[8] the audiometer of D'Arsonval;[9] a device for measuring hearing by R. Panse;[10] an instrument by W. De Bechterew;[11] an *accoumetrie metrique* by Tretop;[12] an apparatus for measuring auditory acuity based on mechanically produced vowels, by Robin;[13] etc. Among such devices, also may be classified instruments such as the well-known Politzer Hörmesser, the watch test, speech and whisper tests; in fact, all those methods and ways for testing hearing which depend on empirically established norms, which are not interchangeable as among different investigators. Such devices have their value in individual laboratories and clinics, where only semi-quantitative results are required and where opportunity is afforded for measuring and establishing, once and for all, the hearing equivalent of the instrument in use. For purposes of investigation, however, they answer but poorly, in that it is never possible for other investigators to review and verify any experimental conclusions reached.

Among the first work done to measure, quantitatively, the intensity of a sound in objective units—at least relatively objective units—was that by Vierordt,[14] in 1878. This investigator concerned

[6] *University of Iowa Studies*, **2**: 55. 1899.
[7] *Science*, **19**: 959. 1894.
[8] *Arch. Int. Laryn.* **15**: 96.
[9] *Arch. Int. Laryn.* **15**: 96.
[10] *J. of Laryngol.* **19**: 534.
[11] *Arch. de Psych.* **5**: 108.
[12] *Bull. de Laryng., Otol., etc.* **8**: 20.
[13] *Bull. et Mem. Soc. d'Anthropol.* **3**: 209. 1902.
[14] Das Mass der Schallstärke, *Ztsch. f. Biol.* **14**: 361. 1878.

himself with the question of the relation between the height of fall of a ball and the resulting sound intensity. Vierordt believed he had established an experimental formula by which could be determined in relative terms the intensities of two succeeding sounds. Vierordt's work was later reviewed by Oberbech,[15] who established experimentally the formula $i = ph^e$ instead of the formula $i = ph^c$ which Vierordt had proposed for expressing the relation between the sound intensity and fall-height; where "*c*" is a constant depending on the construction of the instrument, "*h*" the height of fall, "*p*," the weight of the ball and "*i*" the intensity of sound. This formula was again reviewed in Wundt's Laboratory in 1881 by Tischer who showed experimentally that a relation between the height of fall and the intensity of the resulting sound is only roughly accurate and such as to be impossible of expression algebraically. Furthermore, the relation is one which it is necessary to establish independently for every ball and instrument used. Some such device, were it possible to state the relation between the falling height and the resulting sound intensity, would be admirably adapted for auditory testing but, for the present at least, it lies beyond the possibilities of a quantitative statement.

The methods for measuring the energy of sound in physical units have been numerous. Relatively loud tones have sometimes been employed in determining the ear's sensitivity. By this method the subject is removed to such a distance from the source of sound that it is just no longer audible. Then by calculating the energy of the sound emitted, and knowing the distance between the subject and the sonorous source, the intensity of sound at the ear may be easily reckoned. This method was employed by Toepler and Boltzmann,[16] who were first to determine the absolute sensitivity of the human ear. On the strength of Helmholtz's generalizations, they calculated the quantity of sound energy leaving an open organ pipe, while Wolf pursued the same method by calculating the energy going out from a bottle over which a blast of air was made to pass, giving rise to a loud shrill tone. The method assumes that *all* energy consumed by the open organ pipe or sounding bottle passes over into aerial sound wave energy. Knowing the pressure of the wind blast playing upon an organ pipe or bottle; the quantity of air consumed; the distance between the subject and the tone center; it is simply a matter of arithmetic to determine the maximum condensation of an air wave reaching a subject's ear.

So far as I have been able to discover, only two remaining devices

[15] *Wied. Annal.* 13: 254. 1881.

[16] See Rayleigh, "The Theory of Sound," 1896, Vol. II., p. 433.

have been employed to arrive at a quantitative *Hörmass:*—the tuning fork and the telephone. The tuning fork has gained prominence as an instrument for testing hearing, I believe, largely because of its efficiency in a functional hearing test. For this purpose it impresses me as being rather a superior instrument. But it is well to bear in mind the distinction between a test's efficiency functionally and its psychological value in testing individual differences. In a functional hearing test, according to the standards set by modern otological practitioners, such devices are required as will measure hearing efficiency for different regions of the tonal scale, and particularly the ear's relative acuity for all variations in pitch found among the tones employed in speech. A scientific test for comparative hearing acuity on the contrary concerns itself with only the relative sensitivity of individuals as regards some one point of the hearing scale. A determination of an individual's functional hearing consequently involves many problems which are found not to enter into a test which seeks only to point out individual differences in the sensitivity of the ears of any group. Continental European otologists, however, employ tuning forks almost altogether both in their tests for general hearing acuity and for locating islands of deafness and other functional disturbances.[17]

To Lord Rayleigh,[18] we owe the credit for first deriving a formula for measuring the sound energy that is given out by a tuning fork in vibration. Rayleigh's formula contemplates a microscopical measurement of the amplitude of the fork's vibration.[19]

[17] See in this connection: Bezold, "Functionelle Prüfung," 1897, S. 121; also *Arch. of Otol.* 25: 384. 1896; 36: 37. 1900. M. Paul Robin, "Appareil pour mesurer l'acuité auditive," *Bull. et mem. soc. d'anthropol.* 3: 209. 1902. Ostmann, "Zur quantitative Hörmass," *Arch. f. Anat. u. Physiol.* 1903, S. 321; also by the same author *Ztschr. f. Ohrenhk.* 51: 237. 1906. Zwaardemaker and Quix, "Schwellenwerth und Tonhöhe," *Ztschr. f. Psychol. u. s. w.* 33: 415. 1903. L. Jacobson and W. Cowl, "Darstellung und Messung Schwingungsamplituden," *Arch. f. (Anat. u.) Physiol.* 1903, S. 1. Many others might be mentioned, but these are sufficient to indicate the European interest in the tuning fork as a measuring instrument of the ear's hearing power.

[18] "Theory of Sound," Vol. II., p. 437; also, "Amplitude of a Just Audible Air Wave," *Phil. Mag.* 38: 365. 1894.

[19] Where "E" is the total energy given out by a tuning fork in motion, its value may be obtained from the following formula:

$$E = \tfrac{1}{4}\, plw \times \frac{dn}{dt} = \tfrac{1}{4}\, pwl \times \frac{\pi^2}{T^2}(2n)^2.$$

Where "l" is the length, "w" the width, and "p" the cross-sectional area of one of the prongs of the tuning fork, "n" the displacement at one of the vibrating ends of the prongs, and "T" the time in fractions of a second, of a single vibration.

For measuring the smallest audible tone when the subject is stationed in proximity to the testing instrument, this method does not suffice in that the displacements of the ends of the prongs are too small for microscopical measurement. Recently, however, Wien derived a formula applicable to a tuning fork, whereby the energy radiated, at any given moment, may be stated in terms of the time of the fork's vibration, if only the initial amplitude be known. This formula is based on the law of the dampening or dying-out rate of tuning forks. The dampening of a tuning fork has been found to follow the law, $a \times e^{-ht}$, where "a" is the initial amplitude, "h" the dampening factor and "t" the time the fork has been vibrating. At any given moment, therefore, the relation between the amplitude of the fork's vibration for the experimenter and the subject, respectively, can be stated by the formula:

$$\frac{a^2(\text{Subject})}{a^2(\text{Experimenter})} = e^{-2h\,(t_{(\text{Subject})} - t_{(\text{Experimenter})})}.$$

With such a formula, it is necessary, only once for all time, to determine the dampening factor "h" for each fork employed, in order to have a quantitative hearing measure at all times serviceable for use.

By computing the energy proceeding from a tuning fork, Lord Rayleigh[20] found that for a tone of 512 vibrations (double) a condensation of 4.6×10^{-9} sufficed to excite a just audible tone, in case of a normally hearing subject. According to Zwaardemaker[21] and Quix, the quantity of the energy necessary to excite a just audible tone of the same pitch is 1.30×10^{-8} ergs. Wead got the figure $1{,}100 \times 10^{-8}$ ergs. Wien with tuning forks placed the value at 612×10^{-8} ergs. These quantities, it will be noted, are small in the extreme, and such as to baffle all except the most delicate and painstaking measurements.

Work with the telephone has been very meagre, if we except some experiments of a purely physical sort directed toward determining the sensitivity of instruments for speech transmitting purposes.

Ferrais,[22] in some experiments published as long ago as 1877, found that an electrical current of 7×10^{-9} amperes (528 D. V.) was sufficient to produce a sensation of hearing. Preece[23] found the minimum electric current audible in a telephone to be

[20] *Phil. Mag.* 38: 365. 1894.

[21] *Ztschr. f. Psych.* 33: 416. 1903.

[22] *Atti della R. Acad. d. Sci. di Torino*, 13: 1024. 1877.

[23] *Brit. Assoc. Report*, Manchester, 1887, p. 611.

6×10^{-13} amperes. Tait[24] found for a tone of approximately 500 D. V. a current 2×10^{-12} amperes only was required to excite an auditory sensation of tone. And Lord Rayleigh,[25] as a result of some careful and extended experiments, placed the value of the minimal current for a sensation of hearing in the telephone, at 7×10^{-8} amperes, for a tone of 512 D. V. Lord Rayleigh presented a means for evaluating the actual energy given out by a telephone in use. For a tone of 512 D. V., the quantity of energy given out by the telephone for a tone of threshold value was practically that which he received when the tuning fork was the auditory excitant, namely, 4.6×10^{-9} ergs per sq. cm. area at the opening into the ear. Rayleigh's method for translating the electrical potentials employed in producing a tone of threshold value into sound intensity units is rather complex, involving some difficult mathematical calculations. Essentially, however, it consisted in a measure of a telephone plate's amplitude of excursion, from which was derived a law showing the relation obtaining between these and changes in electrical potential. Although Lord Rayleigh found that a telephone plate registers differences in electrical current as small as it is possible to measure with a galvanometer of more than ordinary sensitivity, and that, therefore, the change in electrical potential in the telephone is at once a measure of the differences in the intensity of the sound leaving such an instrument, he suggested no means for evaluating concretely intensities of sounds in terms of the excursion of the telephone plate alone. This work remained for Max Wien.[26] Wien based his computations on the assumption that a telephone plate, in an instrument of the unipolar variety, where the edges are perfectly clamped, executes movements which are comparable to those of circular clamped membranes. Wien derived a formula whereby the resulting intensities of the tones may be directly computed, when the extent of the oscillations of the center of the telephone plate is known. According to this formula, it is possible to express the condensation of a sound wave leaving a telephone, at any point in space, directly as a function of the amplitude of the plate's excursion at its middle point, or indeed, the same may be said of the energy of a sound wave at any distant point. The formula, I have neither the inclination nor ability to verify. But Wien, like Lord Rayleigh, in the work of actual experimentation, based his computations on the assumption that the degree of electrical poten-

[24] *Edin. Proc.* **9**: 551. 1878.

[25] "The Theory of the Telephone" and "Minimum Current Audible in a Telephone," *Phil. Mag.* **38**: 295; also 285. 1894.

[26] "Die Empfindlichkeit des menschlichen Gehörorgane, *Pflüger's Arch.* **97**: 41. 1903.

tial is directly a measure of the intensity of a sound as it leaves a telephone. This, however, seems to be not wholly a settled principle. It is a question which has only recently again been opened in the psychological laboratory of the University of Michigan,[27] so, perhaps, this may serve to explain some of the unusual results which Wien reports.

For a tone of 500 D. V., Wien obtained a value in amperes of 3.6×10^{-11}, as the current strength essential to produce a just audible sound in a telephone, whereas, Lord Rayleigh had worked out the value to be 6×10^{-9} amperes. Wien found, moreover, for a tone of pitch 3,200 D. V., that a pressure difference in the air wave, at the ear, amounting to only 1.4×10^{-11} cms. is sensed by our organs of hearing.[28]

In some experiments, to determine roughly the relation between the intensity of tones necessary to hearing and the hearing of speech, Wien [29] discovered that even if the condensation value of a sound necessary to excite a just noticeable sensation of hearing had to be increased 10,000 times, the hearing for speech is only slightly interfered with. One of Wien's subjects, who was hard of hearing, but who could hear loudly spoken words, required an increase in the intensity of the sound necessary to just excite an auditory sensation, of 10,000,000 over that for Wien's own ear and those of some of his fellow workers in the laboratory. I am unable to criticise Wien's data in this regard, on account of the many factors involved in his elaborate apparatus, which are not clearly described in his published results. His figures are, nevertheless, far in excess of those which I have been able to secure with partially deaf subjects, as will become apparent from the distributions of subjects on the basis of their keenness of auditory sense, to which I shall have occasion to revert frequently in the pages which follow.

[27] See "The Telephone and Attention Waves," G. L. Jackson, *J. of Phil., Psych., etc.* 3: 602. 1906.

[28] Professor Webster's "phone," an elaborate mechanism for generating tones of determinate vibration frequency and intensity, also utilizes a circular membrane as the sonorous source. But the instrument, though possessing commendable qualities, is not adapted for auditory acuity measurements under circumstances which make it necessary for the subject to be near the instrument. See Webster, Boltzmann-Festschrift, 1904, p. 866.

[29] *Loc. cit.*, p. 34.

CHAPTER VII

The Instrument for Measuring Auditory Acuity

In the selection of a device for the measure of auditory acuity, there were certain definite limitations which governed the choice to be made. Almost of necessity, the tests would have to be made in buildings and rooms more or less open to the public, and, if it be remembered that there was scarcely a room at the Exposition through which hundreds of people did not pass daily, it will not be difficult to apprehend that any auditory test which depended upon air conduction and a variation of the distance between the subject and the source of sound, as a measure of relative acuity, was at once removed from the realm of choice. In this connection it may be well to recollect also that, to a large extent, we were dependent for subjects upon these very conditions which limited the effectiveness and scope of our work—the crowds of people who passed through our rooms day after day and offered themselves as subjects for experiment. Of course, this precluded the possibility of making measurements in the night or, perchance, on Sundays when there was a maximum of quiet on the World's Fair Grounds. The strikingly advantageous feature attaching itself to a study of some problem at a place where crowds congregate rests in the fact that the study can be made more extensive. Consequently, several very significant phases of the problem of auditory acuity which suggested themselves to me had to be neglected. Chief among these was the problem of the relative acuity of different races for significant and non-significant sounds. This was very unfortunate, too, it seems to me, in that sounds have significance for us largely because they have functional—social and economic—values. We shall never be able to state definitely the relative standing of the various races, with reference to auditory acuity, until experimental evidence can be presented based on measures which have taken into account the significance which *meaning* has for sensitivity. Indeed, the barriers cast about me were such as to restrict the selection of devices for measuring the hearing to those which conduct the sound directly into the auditory meatus. Thus, it became a question of one of some three or four types of apparatus.

The first method suggesting itself is the one employed quite generally by European continental otologists—the tuning fork.

A tuning fork is permanently fixed into some substantial base, such as concrete, marble or lead, in order that there may be little or no alteration in the time, intensity or character of its vibration, the initial impulse remaining the same during the successive weeks or months that the fork may be used for testing. Thus mounted, the fork is placed in a sound-proof box, the cover of which can be lifted for giving the initial impulse to the fork. Close to the fork's tone center is fixed a funnel from the apex of which leads a rubber or lead pipe which soon bifurcates, allowing an equal quantity of sound to pass into each. One may lead to the subject's ear, and the other, perchance, to the ear of the experimenter. Knowing the initial amplitude of the fork and its rate of dampening, it is a simple matter of computation to arrive at a formula by which a subject's auditory acuity can be reckoned directly from the length of time he is able to hear the sound. Or, having once for all determined the dying out rate of any fork in question, it is equally easy to formulate a rule for determining the subject's auditory acuity in terms of the lengths of time that the experimenter and the subject, respectively, are able to hear a tone as it dies out—irrespective of the fork's initial amplitude. (See p. 60 for these formulæ.)

Wherever it is possible to be certain of the faithful and intelligent cooperation of a subject in the performance of a test, there can be no question but that the tuning fork method simply and adequately meets all requirements. But these are conditions that are not often fulfilled even with adults, much more rarely so with children of intelligent parentage, still less so in the case of most children as they are found in the public schools, and almost not at all in case of tests on primitive peoples. The language difficulty in communicating to a subject such directions as are essential to an understanding of the *modus operandi*, the lack of interest in the procedure, indifference as to its outcome, fluctuation of the attention, especially in the presence of very faint stimuli, and frequently willful deceit, all are factors which make uncertain results that depend on a subject's statement of his own subjective experiences. For these reasons, not to speak of the peculiar perceptive difficulties, illusory effects, hallucinations, etc., attending the centering of attention on relatively pure and continuous tones, the tuning fork device was rejected.

Some consideration was also given to a phonographic method of communicating auditory stimuli, first suggested by Bentley.[1] This method, to be sure, possesses the marked advantage of allowing the use of significant stimuli, such as spoken numerals instead of meaningless tones or noises. By the use of certain carefully selected[2] words possessing vowel and consonant combinations, whose tone and intensity values have been determined, it might be possible

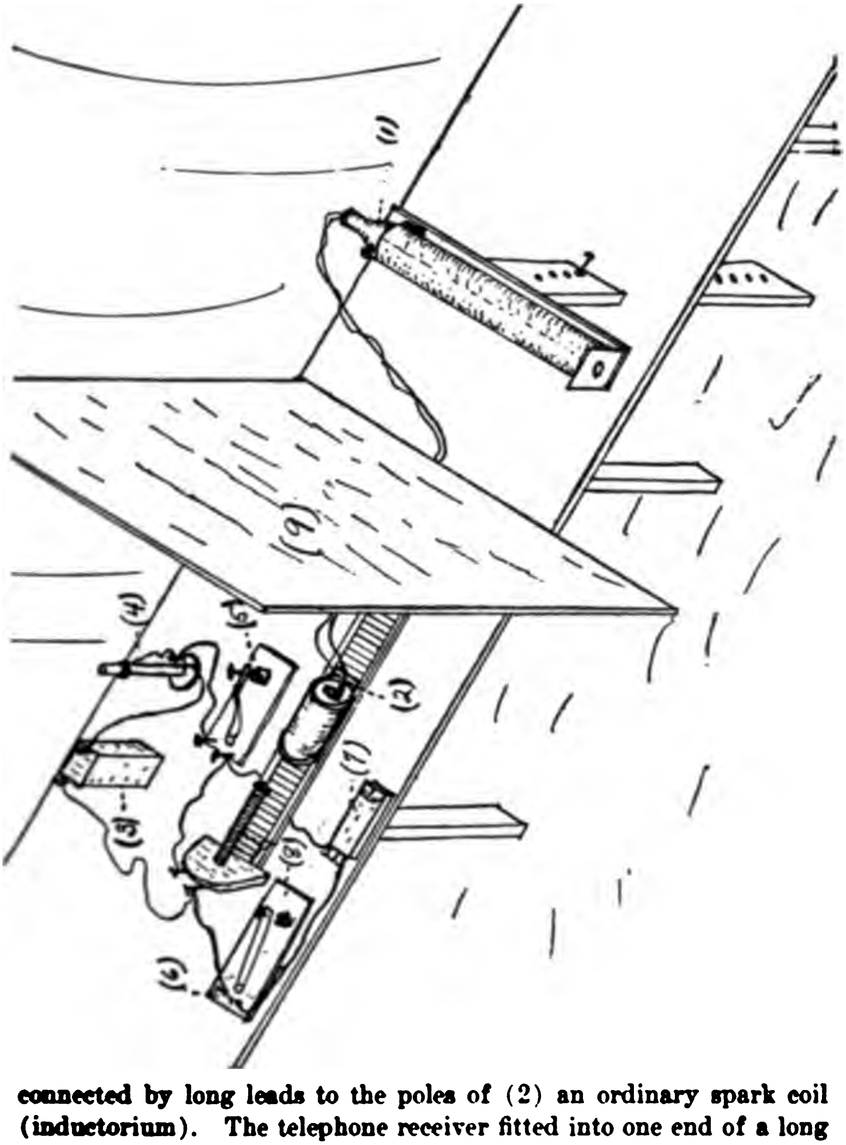
[1] *Science*, N. S. 19: 959. 1894.

[2] See Andrews, *Amer. J. of Psych.* 15: 26. 1904; Wolf, "Ohr und Sprache"; Bezold, "Functionelle Prüfung."

not only to measure the acuity but the range of the ear's functioning. Difficulty, however, is experienced if one seeks to state his measurements in quantitative terms. Moreover, it is impossible to secure a hard, phonographic record that will retain its tonal character after any considerable use. Certain individuals, too, experience considerable difficulty in hearing a phonographic reproduction, as many do in understanding conversation over a telephone. Such objections to the use of a phonograph audiometer as have just been outlined, make its use for measuring primitive peoples of questionable value.

The device found to be most serviceable, though not entirely free from objections, was a form of the telephone. The telephone device was favorably considered, chiefly because Wien had shown how the intensity of the stimuli transmitted to the ear from the telephone receiver can be directly and objectively measured. If such a consummation was within the range of probability, it was hoped to employ in the extended research of the auditory acuity of the different races which I was called upon to make, some means whereby a definitely quantitative statement might be made of the results obtained. It is in this latter particular that the classic work of Dr. Charles Myers on the Papuans is defective, together with practically all other data on hearing heretofore published. With the use of the telephone receiver, the character of the stimulus I chose to employ was such as is produced by the opening and closing of an electric circuit, of which the telephone forms a part. In other words, it is a metallic click which, to be sure, is a sound whose components are not in any definite harmonic relation, and, consequently is what is characterized as a noise, in contradistinction to a tone. Much, notwithstanding, may be said in favor of a sound of such a character. In the first place, since its range of stimulation is large, it is more easily heard, and less fatiguing than relatively pure tones, or even clangs whose tonal elements form some sort of a harmonic series. Noises, too, are more tangible. They have more character; they possess various phases and elements to which the mind can attach itself during the successive moments that they are being held in the focus of attention. Then too, they have much in common with spoken language, in that all of the consonants are sounds whose character can be expressed as inharmonic. However, in that they are non-significant and carry no meaning, to that degree they are relatively less adaptable for general auditory tests. This is a condition that I was able to discover no means of avoiding altogether, although, to a certain extent, the end was attained by the manner in which the stimuli were presented to the subject.

The apparatus, as a whole, is somewhat of a departure from others which have been employed in auditory acuity tests, hence, a more or less detailed description of its several parts is advisable. The parts of the apparatus in gross[3] were (1) a telephone receiver



connected by long leads to the poles of (2) an ordinary spark coil (inductorium). The telephone receiver fitted into one end of a long pasteboard tube, at the other end of which was attached a cushion with a central perforation, against which the head and ear were

[3] The numerals refer to the accompanying figure.

to rest snugly and comfortably. This tube measured a meter in length and 8 centimeters in diameter. To the primary poles of the inductorium were attached leads connecting it with (3) an ordinary lead accumulator (storage battery). In this primary circuit were (4) an ordinary resistance coil; (5) a "make and break" device; (6) a shunt circuit in which was placed, (7) a Weston volt-ammeter, and (8) a switch which allowed the current to be sent through the "make and break" key or through the shunt circuit and the volt-ammeter, as might be desired. Between the transmitting device and the telephone receiver was interposed (9) a large double walled pasteboard screen. The entire device ready for operation is illustrated diagrammatically in the figure.

The Induction Coil.—For bringing about changes in the electrical potential of the secondary circuit, through the telephone, a type of spark coil was employed which permitted the sliding of the secondary coil along a graduated scale farther and farther from the primary coil. The range of graduation covered 100 centimeters. (See diagram.) As is well known, by removing the secondary coil from the primary, the strength of the current in the secondary circuit is progressively decreased. With a relatively weak current, *e. g.*, with a voltage of about 2 and amperage of 0.5, in the case of my own ear, the secondary coil must be removed from the primary on an average to a distance in the neighborhood of 75 cm. before the click ceases to me audible. Thus, it is seen, a considerably wide range is afforded within which the extremes of audibility of any group may find a place, and, obviously, a sufficiently wide distribution is given to the data for the purpose of making comparisons.

The Storage Battery.—It is a difficult matter to secure a type of wet or dry electrical cell which will give a perfectly uniform current, even during the few moments that a hearing test might be given. On this account, I induced the Exposition company to purchase for me lead storage batteries (accumulators). One of these cells was placed in the circuit at a time; the other, in the meantime, being free for charging. When charged to its full capacity, each cell possessed an electromotive force of about 2.2 volts. However, the potential rapidly fell to about 2.0 volts, through internal leakage, but there it remained, with the usage I gave the cells, for several days. It is held that accumulators do better work when not used to their full capacity. Some resistance was therefore always placed in series with the primary induction coil and the battery. Almost uniformly, throughout the entire series of tests, the current passing through the primary circuit

measured 0.5 amperes and 1.9 volts. The current was measured by means of the Weston volt-ammeter, placed in the shunt circuit, before taking the measure of the auditory acuity of every subject. The object of the long leads between the telephone receiver and the secondary coil, was to remove the subject so far from the noise of "make and break" key as could conveniently be done, within the limits of the sound booth.[4] Thus, almost any sound that might arise from the opening and shutting of the key—the faint spark or the noise attending the mechanical manipulation of the instrument—was beyond the hearing of the subject under examination.

The "Make and Break" Apparatus.—In making and breaking an electric circuit with as strong a current as the one I employed in these measurements, unless particular precautions are observed, a spark occurs which is so loud as to be distinctly audible at a considerable distance from the instrument, and indeed in any part of the sound booth. To avoid this distracting feature, a mercury dip "make and break" key was devised. This, in all essential respects, did not differ from the ordinary telegrapher's key, except that in place of the hard contact, a platinum point was made to dip into a mercury bath on closing the circuit, which prevented the noise of contact. And, to prevent a spark, the surface of the mercury was covered with an extremely thin coating of sweet oil. The whole arrangement was such as to be manipulated, generally, without the least accompaniment of sound. But to make precautions doubly certain, a large screen was interposed between the transmitting device and the subject. This screen served, in addition, to shut off the subject from the view of the experimenter, making it impossible for the latter's movements to be seized upon as cues to the character of the stimuli which were being presented, or for his presence to prove a source of distraction.

Max Wien and Lord Rayleigh had their subjects hold the telephone receiver snugly against the ear. By making the span between the diaphragm of the telephone and the tympanum of the ear air tight, they believed all energy given out by the vibrations of the former would be transmitted directly into the ear to the tympanum and the ossicles. I am not certain that this method does not give rise to a molecular transmission of sound through the bones of the skull. I desired to avoid bone conduction, if possible, and therefore placed, at the far end of the pasteboard tube away from the telephone receiver, a soft leather cushion against which the ear might rest easily and yet be shut practically air tight into the tube.

[4] For a description of this sound booth, I refer the reader to the foot-note on page 30.

My experience has been, too, and that of those whom I have questioned, that when the ear is pressed snugly against any hard surface or object, such as a telephone receiver, small distracting sounds result which very much interfere with the perception of faint stimuli. They give rise, particularly, to confusing illusions of hearing. This is especially true of those inexperienced in introspection. The noises just referred to, no doubt, are due to molecular disturbances arising from the rubbing of the head against the hard substance, the tremors of the hand in holding the instrument and no doubt from other sources as well. To avoid all these furnished additional reasons for the leather cushion and the removal of the subject's ear to a distance from the telephone receiver.

The Telephone Receiver.—Of considerable importance in a test of this character is the form and make of telephone receiver employed. The large type is preferable on account of the additional room for windings on the solenoid; for the greater the number of turns of wire on the solenoid, the more sensitive is the instrument to electrical changes; the quicker is the response; and the more sensitive is it to weak electrical currents. A telephone receiver with a single spool of wire surrounding a central magnet which acted over an area of less than a square centimeter on the center of the telephone plate was what I selected. But in place of the central magnet, I installed a piece of extremely soft iron, which would retain relatively no magnetism when not in use. I did this, first, to avoid the error due to changes in the magnetic character of permanent magnets from day to day, and, secondly, to do away with the factor of self-inductance, which so frequently enters as a distributing element when telephones are employed for delicate work. It were better to have no core at all, but the effect of the central core is to simplify the character of the tones given out and, consequently, it can not safely be dispensed with.

It has frequently been observed that differences in the tension, with which the cap is turned on to an ordinary telephone receiver, decidedly influence both the intensity and the character of the tones that are given out. To obviate differences in this respect, I decided to fix permanently the telephone plate to the instrument I employed. Thus the distance between the soft iron core, or temporary magnet, and the diaphragm of the telephone would remain constant throughout the whole series of tests. In the instrument as purchased, the plate rested upon a metallic base, the cap at the same time serving to hold the plate firmly upon its base, and to retain the active parts within the hard rubber casing. I removed the cap entirely as it would be of no service in the testing of hearing, and

fitted over the diaphragm a small steel ring which I fastened firmly and permanently by means of screws to the metallic frame work of the instrument, thus causing the telephone plate to retain the same position and tension at all times.

So much for the instrument proper. But something needs to be said of the arrangements of the parts in testing. On one side of the screen stood the experimenter, with the induction coil, "make and break" key, the alternator, the ammeter-voltmeter in the shunt circuit, before him—over all of which was suspended a small incandescent electric bulb which furnished the illumination. On the other side of the screen sat the subject—his head resting easily against the leather cushion, from a perforation in the center of which the sound entered the ear being tested; the other ear being meanwhile stopped with cotton.

CHAPTER VIII

The Graduation of the Instrument

In this section a question will be considered which is very largely a matter of physics in that it is concerned with the graduation of the telephone apparatus employed in all my hearing acuity tests. The question is of vital importance. Indeed, the exact graduation of the instrument employed in a hearing test should be the chief concern of an experimenter, and particularly is this true, when an attempt is made to state conclusions in terms of interchangeable units. Studies of hearing acuity in which the telephone method has been used, and in which there has been an attempt to translate the auditory acuity of subjects measured into terms of physical units, have been few indeed. Ferrais,[1] Preece[2] and Tait[3] were satisfied to record their conclusions in terms of the fraction of an ampere required to produce an auditory sensation. On the other hand Rayleigh,[4] Wien,[5] Kempf-Hartmann[6] and Jackson[7] have translated their data into terms of ergs (centimeter-gram-seconds). Kempf-Hartmann and Jackson employed a reflecting mirror device for measuring the excursion of the telephone plate, a method which permitted of readings down to an excursion of 0.2 mm. only. Wien and Rayleigh's writings, therefore, alone are of interest as being historically connected with that of mine.

Lord Rayleigh reported some experiments on the sensitivity of the telephone as an instrument for producing delicate shades of difference in the intensity of tones, while Wien employed a telephone in his experiments on the relative sensitivity of the ear for tones of different pitch values. Lord Rayleigh, by measuring microscopically the excursion of a telephone plate under varying conditions of electrical current, discovered that a telephone of the unipolar variety is capable of registering differences in sound intensity as small as a galvanometer of the same number of windings of wire in the solenoid is capable of recording. By inference Lord

[1] *Atti della R. Acad. d. Sci. di Torino,* **13**: 1024. 1877.

[2] *Report Brit. Assn.* (Manchester), 1887; 611.

[3] *Edin. Proc.* **9**: 551.

[4] *Phil. Mag.* **38**: 285, 295. 1894.

[5] *Annal. d. Physik,* **4**: 456. 1901; *Pflüger's Arch.* **97**: 1. 1904.

[6] *Annal d. Physik,* **8**: 481. 1902.

[7] *J. of Philos., Psychol., etc.* **3**: 602. 1906.

Rayleigh concluded that the current changes are at once proportional to the force of the resulting sound waves and that to measure the intensity of a sound wave leaving a telephone it is necessary only to have a measure of the strength of the electrical current used in generating it. It was this extreme sensitivity of the telephone, which places it on a par with the galvanometer, that influenced me to employ it in the measurements of the hearing of primitive peoples. Wien, after verifying Lord Rayleigh's results with several telephones, derived a formula whereby the energy emitted by a telephone plate in vibration, is stated in terms of the extent of the excursion of its middle point.

In a hearing test it is always desirable to have the unit of measurement as accurately defined as possible. Acoustically, the unit is defined as the quantity of sound energy passing a square unit surface (usually 1 sq. cm.), perpendicular to the line of a sound wave's progression, in a unit of time (1 second). Likewise, the intensity of a sound at any distance from a sonorous body is expressed in the following algebraical formula:[8]

$$E = \tfrac{1}{2} p.\, a. \times \left(\frac{2\pi}{L}\right)^2 \times A^2,$$

where "E" is the intensity of the sound in ergs; "p" the density of the medium through which the sound passes; "a" the velocity of sound's propagation in air at 0° C.; "L" the length of a single sound wave; and "A" the amplitude of the sound wave's vibration.[9]

In the formula, the "A" is a factor whose value it is always difficult to ascertain. Either the quantity of sound energy leaving the sounding body must be known or the degree of condensation at some point distant from the source must be measured.

Wien[10] used both methods, employing the latter as a check to the former. In the determination of the value of "A" at a distance from the source of sound the condensation was measured by observing the effect of a sound wave on a rubber membrane stretched across a resonator pitched to respond to the tone of the sounding source. But the method can not be said to be very accurate. It is simpler to express the intensity directly in terms of the quantity of energy leaving a sonorous center—if this quantity can be de-

[8] Rayleigh, "Theory of Sound," Vol. II., p. 468.

[9] The factor indicating the decline in sound intensity with distance from sound source has been purposely omitted, for the reason that the rate of decline is still an unsettled question. The best authorities seem to favor a decrease directly as the distance. See Webster, Boltzmann-Festschrift, 1904, p. 866.

[10] *Pflüger's Arch.* 97: 30. 1903.

termined—and to compute from this the amount passing any given area at a point removed from it.

Instead of using the quantity of energy, it is customary in acoustics to express the force of a sound wave in terms of its condensation. For the convenience of the reader in the discussions which follow, I shall employ both figures.

Helmholtz established certain formulæ, whereby the intensity of sound emanating from circular vibrating membranes, with firmly clamped edges, can be calculated. One of these formulæ was adapted to a membrane of the character of that found in a telephone receiver by Wien,[11] if the instrument is of the unipolar type, in which event it is presumed to emit longitudinal sound waves of the sinus variety. The formula expressed algebraically is,

$$\Delta = 0.147 \times \frac{K}{c^3} \times \frac{(2\pi N)^2 \times R^2 \times a}{d}$$

Where "Δ" represents the condensation; "K" a constant, the correction for specific heat; "c" the rate of propagation of sound in air at the temperature obtaining when the measure is made; "N" the vibration frequency of the tone emitted; "R" the radius of the telephone plate, freely vibrating; "d" the distance between the telephone and the ear of the observer; and "a" the maximum extent of the excursion of the middle point of the telephone plate. Of these factors, the value of "K" may be computed once for all from the familiar formulæ for temperature corrections;[12] the values of "c," "d," "N" and "R" also may be either directly measured or computed, leaving only the value of "a" for various sound intensities to offer any serious problem. This value necessarily must be measured independently for every variation in the intensity of tones employed. The derivation of the formula involves some complicated mathematical deductions which I shall not attempt to elaborate. Its value and general utility in a hearing acuity test where conditions make it advisable to employ a telephone for producing the auditory stimuli, are obvious. The hearing data to be hereafter presented have been computed from it. For purposes of pointing out individual differences, however, its validity is inessential, inasmuch as in any case the figure representing the condensation is directly proportional to the amplitude of excursion of the middle point of the telephone plate.

If, instead of the condensation, it is desired to know the actual quantity of energy passing a square centimeter area perpendicular

[11] *Loc. cit.*, p. 46.

[12] Wüllner's "Experimental Physik," Bd. 1, s. 928. 1894; and *Phil. Mag.* **38**: 256. 1894.

to the line of a sound wave's progression at any distance from its source, it may be found directly from the figure giving the condensation. According to Lord Rayleigh,[18] the sound energy passing a unit area is equal to:

$$E = \frac{\rho a_t^2}{2k} \times \Delta^2$$

Where "ρ" is the density of air (.00129 gm.) "a_t" is the velocity of sound in air as above, "Δ" is the condensation and "k" is a constant representing the correction for specific heat.

Conditions were wholly unsuited for graduating the hearing instrument at the Exposition, but I felt that no inaccuracy would result in case the graduations were made at some subsequent time, if only the electrical conditions might be reproduced to correspond exactly with the originals for each hearing measure taken. In making the original records of the hearing acuity of the different individuals, therefore, I registered the data in terms of the position of the secondary coil as regards its distance from the primary of an induction circuit also making record at the same time of the character of the electric current that I was employing. The latter record was made in both amperes and volts, a Weston volt-ammeter being used for the purpose.

The problem of the measurements of the excursion of the telephone plate is one of no small concern. Indeed, it is a task of great difficulty and one that must be approached with patience and more than ordinary precision of method, if the error of measurement is to be kept within workable limits. Like Lord Rayleigh and Max Wien, I made these measurements with the aid of a compound microscope. The method was as follows: To the center of the telephone plate was fixed a finely drawn out glass tube, to serve as an object upon which to focus the microscope. In order to clarify the image in the microscope, the tip of the glass tubing was first dipped into some red ink, which caused the red point to stand out clearly in the field of view. The tube was then attached to the telephone plate by setting it into a drop of shellac, which when dry presents a hard and inelastic adhesive, and which will transmit vibrations in exactly the same form in which they are received. At first an attempt was made to do the measuring with an ordinary compound microscope by mounting the telephone receiver in such a way as to allow the glass tubing to extend horizontally under the ocular of the microscope. But on account of the constant vibratory movements which the glass rod executed, even in the absence of an electric

[18] "Theory of Sound," Vol. II., p. 469.

current, the use of the vertical type of microscope had to be abandoned. I then selected a Bosch and Lomb demonstrating microscope which I mounted horizontally into a mass of plaster of Paris, and into the same mass I mounted the telephone receiver with the glass rod extending downward in such a way that the tip of the tubing was in the microscopic field of view. The microscope was fitted with a No. 1 ocular and $\frac{1}{12}$ objective, which gave a magnification varying only by a small fraction from 500 diameters. The ocular was supplied with a micrometer scale, making it possible to make readings which might be translated directly into micromillimeters.

Even with the precautions just indicated, it was found that satisfactory measurements in a down-town building were impossible, owing to the jars and vibrations arising from traffic on the streets below, which affected the movements of the glass filament mounted upon the telephone diaphragm. I therefore removed the entire apparatus to a place in the country, wholly free from all external disturbances.

It had not occurred to me, when measuring the hearing of the peoples at the Exposition, that for the threshold of hearing of an individual with ordinary acuity, an excursion of the diaphragm of the telephone would suffice, which measured no more than 0.00000016 centimeters; a distance, indeed, so small as to exceed optical possibilities of measurement, and necessarily, beyond the measuring capacity of the most powerful microscopes. This, then, was a serious situation. Except for the lower acuity values, the measurement of the excursion of the telephone membrane would be either wholly impossible or accurate within the region of a large probable error. Moreover, when the limits of the powers of the compound microscope are exceeded, other, reflecting, devices are even more useless. A way to circumvent this difficulty finally presented itself to me—what may be designated as a method of extrapolation. This method consisted in making microscopical measurements for those positions of the secondary coil where it was possible to do so accurately with the electrical currents as they obtained at the Exposition, while the hearing records were being made, and, for other positions of the secondary coil, to increase the electric current to the point where it was possible to make satisfactory microscopic measurements. This method was pursued for every variation in electric current that was employed in the hearing tests.

In the first column of the table on page 81, are tabulated these measures of the excursion of the telephone plate for the different positions of the secondary coil, when a current strength of 1.9 volt and 0.5 ampere was employed. Under such conditions of current

it will be seen it was possible to make microscopic measurements for positions of the secondary coil from 1 to 12 only, the figure "1" here indicating that the secondary coil is removed from the position 0, or that in which the primary coil is wholly within the secondary, by one centimeter. The position 10 indicates that the secondary coil is removed by 10 centimeters from the zero position, and so on. Beyond the reading 12, the diaphragm excursions were so small that they could not be accurately evaluated from the readings on the micrometer scale. In point of fact for the position 12 the excursion amounted to 0.000045 centimeter only, which extended over only about one fifth of a single space on the micrometer scale of the eye-piece of the microscope, and is about as small as can be measured with much certainty.

Each figure given in the table is the average of at least five independent readings. Frequently, too wide discrepancies appeared in the separate readings, in which event the measurements were repeated until a certain degree of harmony was found among them. It is unnecessary to give in detail the several individual measurements from which the averages given in the table were made, and inasmuch as some twenty different strengths of electrical current were used in the original hearing records, the tabulations of all would alone cover too many pages. The inconstancy in electrical current arose from the fact that it was impossible to keep the storage batteries, which supplied the current, up to full strength from day to day. No inaccuracy, however, need result from this except that which might be occasioned by certain errors of observation in different microscopical measurements, which need not, in any case, exceed 10 per cent., as will appear from the data which will shortly be presented. Only a very few of the hearing records taken were found to be so poor that a current intensity of such strength was required as that represented by the 8 or 10 position of the secondary coil in the induction circuit. Since the excursion of the center of the telephone plate for positions of the secondary coil further removed than 12 could not be measured directly under normal current conditions as they obtained at the Exposition ($V = 1.9$; $A = 0.5$), the value of the excursion for these subsequent positions had to be derived indirectly, as suggested above.

First, I increased the intensity of the current in the primary circuit to a voltage of 10.0 and an amperage of 0.5; and repeated the measurements as before. This stronger electrical current was drawn from the main of an electric light conduit, resistance in the shape of incandescent lamps being placed in series with this circuit to reduce it to the required strength. With a current of this in-

tensity, it was possible to continue the measurements until the secondary coil reached the position 19. It was found that the excursions of the telephone plate for a current strength of 10 volts were approximately seven times (6.72) those when the voltage was 1.9. The readings for this current intensity are to be found in the second column of the table on page 81. If now the microscopical readings of the excursion of the middle part of the telephone plate for this strength of the electrical current (10 volts) is divided by this figure (6.72) the readings should correspond with those obtained from the weaker current. It is significant that in no case does a result so obtained differ by more than 10 per cent. from its corresponding one to be found in the first column. This indicates that the method gives results which are accurate, at least, to within 10 per cent. With this stronger current, for the first position of the secondary coil, the oscillations of the glass tip were so violent as to extend too far beyond the micrometer scale of the ocular to be read. Beyond the position, 19, the extent of excursion on the contrary was again too small for measurement. For positions beyond this point the strength of the electrical current had again to be increased; the current in the primary circuit being raised to a voltage of 107 and an amperage of 1.1. This was about as powerful a current as I felt justified in sending through a wire of the dimensions of that with which my primary coil was wound, owing to the danger of burning off the insulations. The microscopic readings with this current intensity are to be found in column three of the table on page 81. Excursions of the telephone plate corresponding to positions of the secondary coil nearer than 12, it was again impossible to measure, inasmuch as the extent of its oscillations exceeded the limits of the micrometer scale. At the other end, microscopic measurements were possible to the position of 64 of the secondary coil, that is, until the secondary was removed from the primary coil to a distance of 64 centimeters. There remained about twenty-one of the hearing records of whites and one of Indians in which the secondary coil was beyond this point. The excursions for the remaining positions of the secondary coil, therefore, had to be gotten by some other method. Two suggested themselves.

The first of these subsidiary methods was based on the experimental conclusions reached by Lord Rayleigh[14] and Wien[15] to the effect that a telephone is as sensitive to changes in electrical potential as an ordinary galvanometer is capable of measuring, especially as regards small currents. In keeping with this method, I selected

[14] *Phil. Mag.* 38: 287. 1894.
[15] *Pflüger's Arch.* 97: 11. 1903.

ten intelligent subjects—boys 12 to 14 years old—for whom I determined the average current intensity necessary to produce a tone of threshold value for all positions of the secondary coil from 10 to 75 centimeters removed from the primary. If, according to Lord Rayleigh,[16] the excursion of the middle point of the telephone plate is directly proportional to the electromotive force, the excursion of the telephone plate for positions of the secondary coil where microscopical measurements are impossible may be computed.

In detail, the mode of procedure was as follows: The secondary coil was placed 10 centimeters removed from the zero position and the current passing through the primary circuit uniformly without resistance ($V = 5.0$; $A = 0.5$) was reduced by placing resistance in the circuit until the threshold of hearing was reached for each of the subjects. A record was then made of the number of ohms of resistance required.[17] Then, in order, the same procedure was followed for other positions of the secondary coil up to 75. It seems scarcely necessary to present all these data in detail. In point of fact, the method was not extremely accurate, due no doubt in a large measure to variations in the attentive capacity of my youthful subjects from moment to moment, hour to hour, and from day to day. In general, however, the data secured were such as to justify a favorable conviction relative to the accuracy of the main method employed, for while the variations between the two methods were considerable, the figures gotten from the latter method followed along the same line as those from the first.

The second subsidiary method was based on the assumption that the law of the decrease of the intensity in the secondary circuit of an induction coil holds uniformly, as the two circuits are separated more and more widely. That is, by determining the ratios of the excursion of the telephone plate for the several positions of the secondary coil nearer to the primary than 64 centimeters, and thus determining the rate of the fall, it was assumed that with a method of extrapolation the excursion of the telephone plate for positions of the secondary coil farther removed from the primary than 64 centimeters could be calculated with a fair degree of accuracy.[18]

If we take the telephone excursions as they appear in the third column of the table on page 81, where the strongest electrical potential prevailed, and divide the excursion of the telephone plate for

[16] *Loc. cit.*, p. 287.

[17] The resistance coils used were those of a standardized box, kindly loaned to me from one of the physical laboratories.

[18] For positions of the secondary coil 16 and beyond, the primary was wholly outside the secondary coil, and consequently it would be unreasonable to believe that there would be any change in the law of fall for these positions.

the position of the secondary coil, 44, by that for the position 42, and that for the position 46 by the excursion for the position 44, etc., until the last measurable position 64 is reached, the general fractional rate of decline in excursion is found. I present the separate figures:

.00012 /.00013	0.93	.000064/.000069	0.93
.00011 /.00012	0.92	.000058/.000064	0.91
.000096/.00011	0.87	.000052/.000058	0.90
.000086/.000096	0.91	.000049/.000052	0.94
.000079/.000086	0.92	.000045/.000049	0.92
.000069/.000079	0.87		
		Average rate of decline	0.91

As stated above, if it is assumed that the rate of decline for the last five positions of the secondary coil is the same as for the eleven just preceding as indicated in the data given, it becomes necessary only to multiply the excursion 0.000045 centimeter of the 64 position by 0.91 to have the excursion for the position 66, and hence the excursion of the telephone plate for this position would be 0.000041 centimeter under the conditions of current as they obtained in the readings of the third column. Multiplying 0.000041 centimeter by 0.91 we get 0.000037 centimeter as the excursion of the telephone plate for the position 68. Continuing the same process, the excursion for position 70 is 0.000034 centimeter; for position 72, 0.000032 centimeter, and for position 75, allowing for the increase in interval, 0.000028 centimeter.

It may be noticed that for the positions of the secondary coil removed, respectively, 10, 11 and 12 centimeters from the primary, microscopic readings were secured for three different current intensities. The figures given in the table for each of these positions of the secondary coil, moreover, are the averages of at least 10 independent microscopical readings. Especial care was observed at these positions in order to afford an accurate basis for determining the ratio of excursion of the telephone plate for the three intensities of electrical current used. In Series II., where the voltage was 10, amperage 0.5, the excursion of the telephone plate on the average was 6.72 times as large as in Series I., where the voltage was 1.9, amperage 0.5, and in Series III., where the voltage was 107, amperage 1.1, an excursion on the average resulted which was about 27.8 times as large as in Series II., and just about 187 times as large an excursion as in Series I. When allowance is made at these positions (10, 11 and 12) for differences in current strength, that is, in case the telephone plate's excursion for positions 10, 11 and 12 of

TABLE XIII

EXCURSIONS OF THE TELEPHONE PLATE FOR DIFFERENT CURRENT STRENGTHS

Position of the Secondary Coil	Current Strength Amp.—0.5 Volt.—1.9	Current Strength Amp.—0.5 Volt.—10.0	Current Strength Amp.—1.1 Volt.—107.0	Position of the Secondary Coil	Current Strength Amp.—1.1 Volt.—107.0	Position of the Secondary Coil	Current Strength Amp.—1.1 Volt.—107.0
	cms.	cms.	cms.		cms.		cms.
1				21	0.0011	54	0.000069
2	0.06			22	0.00092	56	0.000064
3	0.011	0.079		23	0.00077	58	0.000058
4	0.0036	0.023		24	0.00064	60	0.000052
5	0.0015	0.009		25	0.00052	62	0.000049
6	0.00072	0.005		26	0.00049	64	0.000045
7	0.00032	0.0024		27	0.00037	66	0.000041
8	0.00023	0.0014		28	0.00034	68	0.000037
9	0.00015	0.0013		30	0.00030	70	0.000034
10	0.000093	0.00061	0.016	32	0.00024	72	0.000032
11	0.000064	0.00045	0.013	34	0.00021	75	0.000028
12	0.000045	0.00028	0.0081	36	0.00019		
13		0.00023	0.0067	38	0.00017		
14		0.00019	0.005	40	0.00015		
15		0.00015	0.0043	42	0.00013		
16		0.00011	0.0034	44	0.00012		
17		0.000094	0.0029	46	0.00011		
18		0.000073	0.0021	48	0.000096		
19		0.000063	0.0017	50	0.000086		
20			0.0014	52	0.000079		

the secondary coil, in Series II. are divided by 6.72 and in Series III. by 187, the results appear as in the following summary:

TELEPHONE PLATE'S EXCURSION

Position of the Secondary Coil	Series I	Series II ÷ 6.72	Greater or less than in Series I	Series III ÷ 187	Greater or less than in Series I
10	0.000093 cm.	0.000094 cm.	1.0 per cent.	0.000085 cm.	8.7 per cent.
11	0.000064 "	0.000068 "	6.2 "	0.000069 "	7.8 "
12	0.000045 "	0.000042 "	6.7 "	0.000043 "	4.5 "
	Average difference between series		4.6 "		7.0 "

Series II. and III. have 10 readings in common, for positions of the secondary coil from 10 to 19. Comparing Series II. with Series III., that is, by dividing the excursions of the telephone plate in Series III. for positions 10, 11 and 12, to 19 of the secondary coil by 27.8, we get the results in the summary below.

From the data just exhibited, it is possible to determine what degree of accuracy may be looked for with reference to the method of extrapolation here employed. It is seen that the average difference in result between the microscopical measurements of the telephone plate with the electrical current as it obtained at the Exposition (voltage 1.9; amperage 0.5) and the next stronger current

TELEPHONE PLATE'S EXCURSION

Position of the Secondary Coil	Series II	Series III.27.8	Greater or less than Series II
10	0.00061 cm.	0.00058 cm.	5.0 per cent.
11	0.00045 "	0.00046 "	2.2 "
12	0.00028 "	0.00029 "	3.6 "
13	0.00023 "	0.00024 "	4.4 "
14	0.00019 "	0.00018 "	5.3 "
15	0.00015 "	0.00015 "	0.0 "
16	0.00011 "	0.00012 "	9.1 "
17	0.00094 "	0.00010 "	6.4 "
18	0.000073 "	0.000076 "	4.1 "
19	0.000063 "	0.000060 "	4.8 "
		Average difference between two series	4.6 "

(voltage 10; amperage 0.5) was only 4.6 per cent. Between the weaker electrical current and the most powerful one employed in the work of graduation (voltage 107; amperage 1.1) the average difference in the result of microscopical measurements amounted to 7.0 per cent. and for the 10 different readings for identical positions of the secondary coil, when the second and highest electrical currents were employed, the average difference in result was only 4.6 per cent. It is likewise worthy of note that the difference between the readings for the same position of the secondary coil, but with different electrical potentials, in no case exceeded 9 per cent. It is, therefore, safe to assume that the microscopical readings for the excursion of the telephone plate as recorded in the third column of the table on page 81, are reliable within 10 per cent. at the outside. Indeed, it is also safe to assume that the corrected figures representing the actual excursions of the telephone plate for the current strengths used in the measurements of auditory acuity do not differ from the true values by more than 10 per cent.

Knowing the excursion of the telephone plate caused by an electrical current of 107 volts, 1.1 ampere for every position of the secondary coil as appears in column III. of the table on page 81 and knowing also from readings of three identical positions of the secondary coil the excess in excursion produced by the current intensity just noted, over that normally obtaining when the hearing records were made (voltage 1.9; amperage 0.5) it is simply a matter of arithmetic to determine the actual extent of excursion of the telephone plate corresponding to each of the original hearing records made. By dividing the values found in column III. of the table (page 81) by 187, the corrected values corresponding to a current strength of 1.9 volts; 0.5 ampere, are secured for every position of the secondary coil from 1 to 75. These are given in Table XIV. below. Inasmuch as an intensity of sound represented by a position of the secondary coil nearer to the primary than 14 centimeters

TABLE XIV

Table Showing the Excursion of the Telephone Plate (a), the Maximum Condensation (Δ) and the Energy (E) in Ergs, Corresponding to Every Position of the Secondary Coil

Position of Secondary Coil	Excursion of Center of Telephone Plate "a"	Condensation of Air Wave Leaving Instrument "Δ"	Energy of Sound Wave Per Sq. cm. at Instrument "E"	Position of Secondary Coil	Excursion of Center of Telephone Plate "a"	Condensation of Air Wave Leaving Instrument "Δ"	Energy of Sound Wave Per Sq. cm. at Instrument "E"
	cms.		ergs		cms.		ergs
75	1.6×10^{-7}	1.4×10^{-6}	5.0×10^{-8}	34	1.1×10^{-6}	1.04×10^{-6}	2.8×10^{-6}
72	1.7 "	1.5 "	5.6 "	32	1.3 "	1.2 "	3.5 "
70	1.8 "	1.6 "	6.5 "	30	1.6 "	1.4 "	4.9 "
68	2.0 "	1.8 "	8.0 "	28	1.8 "	1.6 "	6.4 "
66	2.2 "	1.9 "	9.0 "	27	2.0 "	1.8 "	8.0 "
64	2.4 "	2.1 "	1.1×10^{-7}	26	2.4 "	2.1 "	1.1×10^{-5}
62	2.6 "	2.3 "	1.3 "	25	2.8 "	2.5 "	1.6 "
60	2.8 "	2.5 "	1.6 "	24	3.4 "	3.0 "	2.3 "
58	3.1 "	2.8 "	2.0 "	23	4.1 "	3.6 "	3.3 "
56	3.4 "	3.0 "	2.3 "	22	4.9 "	4.3 "	4.5 "
54	3.7 "	3.3 "	2.8 "	21	5.9 "	5.3 "	7.0 "
52	4.2 "	3.6 "	3.3 "	20	7.3 "	6.5 "	1.05×10^{-4}
50	4.6 "	4.0 "	4.0 "	19	9.3 "	8.2 "	1.7 "
48	5.0 "	4.5 "	5.0 "	18	1.1×10^{-5}	1.00×10^{-7}	2.5 "
46	5.6 "	5.0 "	6.3 "	17	1.4 "	1.3 "	4.3 "
44	6.3 "	5.5 "	7.5 "	16	1.8 "	1.6 "	6.5 "
42	7.0 "	6.2 "	9.5 "	15	2.3 "	2.0 "	1.0×10^{-3}
40	8.0 "	7.1 "	1.3×10^{-6}	14	2.8 "	2.5 "	1.6 "
38	9.1 "	8.1 "	1.7 "				
36	10.0 "	9.1 "	2.1 "				

was not required for any subject tested, values for positions of the secondary coil nearer to the primary than this were omitted from the tabulations.

It will be observed that while the secondary coil was nearer to the primary than 27 centimeters readings were made at intervals of one centimeter, but for positions of the secondary coil more distant, graduations were made only at intervals of 2 centimeters. This plan was followed since obviously the fall of electrical potential along the induction circuit is not directly as the distance. Indeed, it falls very much more rapidly than this, and while the change from graduations at intervals of one centimeter to graduations at intervals of two centimeters does not equate the steps, it does serve to keep the records from being too widely dispersed at the upper end of the curve. The matter of inequality in steps, however, injects no inaccuracy into the final results, so long as basically the values of each position are accurately determined. And, since each position in these tests receives its value in *ergs* of sound energy emitted or *centimeter-seconds* of *condensation* of the sound wave, the question of the number of steps to be made in the tests acts as a matter of convenience in manipulation only. It would make but an insignificant difference in the average of any group whether graduations had been made at intervals of 1 or 2 or 5 centimeters.

The excursions of the telephone plate (a), corrected as outlined above for an electrical current of 1.9 volts, and 0.5 ampere, appear in the second column of Table XIV., on page 83. In the third column are given the values of the condensations (Δ) computed from Wien's formula[19] already given, namely,

$$\Delta = 0.147 \times \frac{k}{c^2} \times \frac{(2\pi N)^2 \cdot R^2 \cdot a}{d}.$$

[19] These formulæ call for certain measurements relative to the values of "k," "c," "N," "R," "a," "ρ," and "d," respectively. "k," which represents the temperature coefficient, is a constant found from the well-known formula of Keyser (*Phil. Mag.* 38: 256. 1894). "c" stands for the velocity of sound in air at the temperature prevailing when the graduations were made. In the experiments under consideration its value was taken as 340.2 M. The radius of the free vibrating area of the telephone plate measured 2.24 cm. The several values of "a," the excursion of the telephone plate at its middle point, appear in the second column of the table. The distance between the ear and the center of the telephone plate "d" throughout the entire series of hearing tests was uniformly 100 cm. However, inasmuch as the ear was sealed into one end of a tube and the telephone into the other, both to a large extent air tight, a value of one centimeter was assigned to this distance. Indeed, it is improbable that the loss of energy in a sealed tube would be any considerable quantity for such a short distance of propagation. The value of "ρ," the temperature coefficient, is 0.00128. "N" equaled 500 D. V.

In the fourth column are given the values in ergs (centimeter-gram seconds) of the quantity of sonorous energy passing a square centimeter area perpendicular to the line of the sound wave's progression. The latter are computed from Lord Rayleigh's formula already given, namely,

$$E = \frac{a^2\rho}{2} \times \Delta^2 \text{ ergs.}$$

CHAPTER IX

METHOD OF CONDUCTING TEST

ALL the measurements for simple auditory acuity were made in the sound room,[1] and consequently under conditions, the most favorable for quiet that it was possible to secure at the Exposition. In order to obtain a correct estimate of an individual's hearing, it is very essential that the test be conducted under circumstances as favorable as possible. It is difficult to keep the attention focused on faint stimuli, no matter through which sense avenue they are received, but faint auditory stimuli are especially elusive. Fatigue of the auditory sense organ results after a moment of stimulation, so that even under the most favorable adjustment of external conditions, it is not possible to continue an auditory test longer than four or five minutes, even with a subject of far more than average intelligence. Hallucinations enter as very disturbing factors. It is a common observation with those who have made tests of the hearing of both children and adults to find that the individual vigorously asserts that he hears the sound used as a stimulus even though the source has been entirely removed. This is especially true of continuous tones, or such as follow in a rhythmical order, as the ticking of a watch, or the regular falling of water drops.

Faint auditory sensations are likewise subject to decided illusory effects. Any extraneous noises are apt to be interpreted as the tone to which the subject is expectantly attending. Such noises as are produced by the scraping of the feet in walking over an earthen, brick or cement floor are especially likely to be heard as the stimulus to which the subject is directing his attention, if a metallic click is the stimulus employed. Noises from the street act in the same way. Those things which tend to be distracting elements with adult Whites are bound to be emphatically so in tests on primitive peoples and younger children, whose power of attention is weaker, and who are, consequently, more easily distracted and are unable to single out one from among a number of somewhat similar stimuli which they will hold at the focus of attention.

To overcome so far as possible the error which might creep in, on account of the elements just enumerated, a check method sug-

[1] For a description of this booth the reader is referred to the foot-note on page 30.

gested by Professor Cattell was introduced. This consisted in having the subject interpret and give back what he received. The test in consequence is a little more than a measure of pure sensation—if a measure of pure sensation is ever possible. Instead of presenting the "makes and breaks" in rapid succession without reference to number or manner, as is ordinarily done with the telegraph key, or the "*make and break*" mechanism of the Seashore audiometer, I gave the stimuli in groups or rhythms; that is, a series might be presented in which two clicks in rapid succession would be followed by a pause of two seconds, the two clicks repeated and so on. Or, the series might be given in singles or in groups of three clicks followed by a rest of a couple of seconds. Graphically, the series might be represented as follows: --,,,--,,,--,,,--,,, etc., in which the dashes represent the order of the stimuli and the commas, pauses or silence. A group of three clicks would be represented by the following scheme: ---,,,---,,,---,,,---,,, etc., and a rhythm of single clicks by the following: -,,,,-,,,,-,,,,-,,,,-,,,, etc. I pursued no set order of presenting the series, so that it might not be possible for the subject to anticipate the answer which he would be expected to give.

The number of clicks to a group, I found, had to be limited to three. I discovered that many of the primitive peoples were unable to count the stimuli following each other as rapidly as did these with any degree of facility in groups larger than two or three. Children, too, I afterward learned, can catch a rhythm of three but experience difficulty with one of four or five.

Such a method of presenting the stimuli, as has just been indicated, in a manner supplies the deficiencies arising from the necessity of employing non-significant stimuli in testing hearing. Indeed, to a considerable degree, the test is one of which the elements are significant; that character being attached to them by the counting operation. The test, moreover, has other advantages. It does away with the necessity of depending upon the cooperation of the subject—a necessity present in almost all other methods for measuring hearing. It presents something tangible, as it were, for the attention to attach itself to. The subject, when the ordinary methods are followed, finds that as the sensation becomes increasingly more faint, it is impossible for him to organize his mental processes to the extent of arriving at a certain conviction as to whether he actually hears the tone or not. Where the method of *reproduction* is followed, this element of uncertainty does not, in any way, enter into the results.

In all cases, I chose as the threshold that point where the subject

failed to indicate accurately the character of the stimuli presented. In the neighborhood of the threshold values, I made it a point to vary the character of the stimulation frequently without changing its intensity. This was done to make certain that the subject's responses were not pure guesses. It was found, however, that in case of almost all persons, there is a subconscious evaluation given to such estimates which are wholly valid. When the subject stated that he was uncertain as to the character of the sensation, whether the ticks came in twos, threes or ones, he was told to express a judgment and it so happened that frequently the subject judged correctly every variation made with a given intensity although he asserted that his estimations were in every case pure guesses.

CHAPTER X

RESULTS

THE nature of the data as regards auditory acuity is such as to make them somewhat difficult to present intelligibly. These data relating specifically to auditory acuity are given both in terms of the condensation of the sound wave leaving the telephone and the actual energy in ergs (centimeter-gram-seconds) exerted by the sound wave over a square centimeter of surface at the same point. Since the energy required to produce a tone of threshold value, in an ear of ordinary sensitivity, amounts to less than a ten-millionth part of an erg, it is at once clear that the data we are working with are comprehensible, popularly, only in mathematical terms. The data to be presented, however, are to be employed for comparative purposes only, so that the absolute values are, relatively, of insignificant moment. To know that one group of people possesses a hearing sensitivity two, or ten, or one hundred times as great as another, does not call for an understanding of the absolute unit used, if only the unit remains constant from one series of measurements to another, and besides, possesses the additive character. The figures representing the condensation as well as the actual quantity of sound energy being dispersed fulfill both requirements, and hence no inaccuracy will result if the reader ignores the fractional factor altogether, and thinks of the results in terms of the first part of the figure only, *e. g.*, in terms of "1.4" instead of "1.4×10^{-9}." And in the eyes of many readers such a method of interpreting the complex data which follow, will contribute both to their clearness and ease of comprehension.[1]

In Table XV. are presented these figures in detail, indicating the race; number of cases included in the average; the average result, stated in terms of atmospheres of pressure, and ergs (centimeter-gram-seconds); the average deviation from this average; and the standard deviation. From the latter, it is possible to compute directly any other measures of the variability that may be desired. The data are given for both the right and the left ear. A word, perhaps, is necessary concerning the make-up of the respective groups. For a test of this kind, as was noted in connection with the

[1] For details relating to the physical graduation of the instrument employed in the acuity test, the reader is referred to Chapter VIII.

data on the upper threshold of hearing, already presented, it was thought best to reject those individual hearing records where there was definite reason to believe that the case was one of pathological hearing. In pursuance of this, therefore, I rejected in this series of measurements the data from every person who consciously had experienced difficulty in hearing. Obviously, so long as the rejections follow some consistent plan, no inaccuracy need result and I do not

TABLE XV

AUDITORY ACUITY

In Terms of the Condensation of the Sound Wave Leaving the Instrument and also in Terms of the Energy in Ergs Leaving the Same

	Right Ear					Left Ear			
	No. of Cases	Average $\Delta = 10^{-9}$	A. D.	S. D.	Average $E = 10^{-7}$ ergs	Average $\Delta = 10^{-9}$	A. D.	S. D.	Average $E = 10^{-7}$ ergs
Whites	151	5.6	3.85	5.02	7.9	7.2	5.06	5.09	13.2
Indians (School)	64	7.5	3.63	5.18	14.2	8.5	4.09	5.79	18.2
Filipinos	137	24.2	14.57	18.30	147.8	26.6	14.46	17.81	178.6
Cocopa Indians	10	7.3	2.86	3.49	16.01	9.0	5.30	6.34	30.2
Vancouver Indians	7	10.01	5.01	5.69	38.1	10.03	5.95	6.66	36.5
Patagonian Indians	3	12.3	8.43	8.97	38.1	17.0	8.59	9.57	73.0
Ainu	8	18.1	11.64	16.38	82.7	17.1	8.71	11.36	73.4
Pigmies	5	10.3	3.55	4.44	26.8	7.5	1.24	1.32	14.2

Δ = condensation of sound wave at the instrument.

E = energy in ergs of sound wave leaving the instrument.

A. D. = average deviation.

S. D. = standard or the mean square deviation.

TABLE XVI

AUDITORY ACUITY

In obtaining the averages given in this table, the lowest 25 per cent. and the highest 25 per cent. of each group were omitted, leaving only the middle half.

	Right Ear				Left Ear		
	No. of Cases	Average $\Delta=10^{-9}$	A.D.	Average $E=10^{-7}$ ergs	Average $\Delta=10^{-9}$	A. D.	Average $E=10^{-7}$ ergs
Whites	78	3.9	0.922	3.84	4.9	1.33	6.06
Indians	33	6.1	1.40	9.61	5.0	1.03	6.31
Filipinos	81	16.5	5.29	68.73	18.8	6.02	89.21

Δ = the condensation of the sound wave at the instrument.

E = the energy of the sound wave in ergs per square centimeter area leaving the instrument.

think that the rejection of the records of some twenty individuals, for the reason indicated, influenced the character of the results otherwise than to raise the average for each group to an appreciable extent. For such large groups as those of the Whites, Indians, or the Filipinos, a sifting of the records, perhaps, would have been unnecessary, but in case of some of the smaller groups, with fewer than ten individuals, any one specially poor record would

TABLE XVII

RIGHT EAR

Showing the Distribution of the Individuals with Respect to Auditory Acuity

Intensity of Sound, $\Delta = \times 10^{-9}$	Whites	Indians (from School)	Filipinos	Cocopa Indians	Vancouver Indians	Patagonian Indians	Ainu	Pigmy
1.4	1							
1.5	3							
1.6	4							
1.8	7							
1.9	6	1						
2.1	5	1						
2.3	9	2						
2.5	6	1	3					
2.8	9	3	1					
3.0	13	2	2					
3.3	9	2	3	1	1			
3.6	9	2	3					
4.0	7	4	2	2			1	
4.5	6	4	2				1	
5.0	6	5	2			1		
5.5	7	4	2				1	
6.2	6	3	4	4	1			2
7.1	5	4	5			1		
8.1	2	7	6		1			
9.1	4	5	8					1
10.4	6	4	7		1			
11.9	5	4	7	1			1	1
14.1	3	2	9		1			
15.7	0	1	10					
18.1	2	0	9		1			1
21.1	1	1	8				1	
25.0	2	1	8			1	1	
29.9		1	7		1			
36.5			6				2	
43.4			5					
52.5			5					
64.8			6					
82.3			3					
99.9			2					

affect the standing of the group to such an extent as to make the figure for the average wholly unrepresentative and false. Yet, in spite of corrections and eliminations, it is quite evident that all pathological cases were not excluded, as appears from a comparison of the data presented in tables XV. and XVI. In Table XVI., I

TABLE XVIII

LEFT EAR

Showing the Distribution of the Individuals with Respect to Auditory Acuity

Intensity of Sound, $\Delta = \times 10^{-9}$	Whites	Indians (from School)	Filipinos	Cocopa Indians	Vancouver Indians	Patagonian Indians	Ainu	Pigmy
1.4	1							
1.5	2							
1.6	3							
1.8	3							
1.9	4	1						
2.1	4	1						
2.3	5	1						
2.5	7	3		1				
2.8	7	2						
3.0	8	3						
3.3	11	4	4		1			
3.6	12	4						
4.0	8	5	2		1			
4.5	8	6	2					
5.0	7	5	4	2	1			
5.5	6	4	3					
6.2	8	2	4	2			1	2
7.1	5	3	4			1		1
8.1	5	3	5	1			1	
9.1	5	3	7					2
10.4	4	2	6					
11.9	5	2	6				3	
14.1	4	2	8		1	1		
15.7	3	1	12		1			
18.1	4	1	11	1	1		1	
21.1	4	1	9	1				
25.0	2	2	9				1	
29.9	3	1	7		1	1		
36.5			7					
43.4		1	6				1	
52.5		1	8					
64.8			4	1				
82.3			3					
99.9			3					
127.2			2			1		
162.5			1					
214.9				1				

rejected the 25 per cent. of the records at the top and the same number at the bottom, leaving one half of all the records distributed normally about the median. Were the distribution of cases normal, such a method of procedure would affect the average result only to a very slight degree. It will be noted on the contrary, however, that the average has been shifted upward decidedly in the case of every group. In fact, this sifting has the effect of almost doubling each average, thus reducing the quantity of energy necessary to excite an auditory sensation, on the average, by one fourth.

In tables XVII. and XVIII. are shown the general distributions of the individual records, as they appear in the several groups.

These distributions have been made in parallel columns to facilitate the study of comparisons. The tables, likewise, show the character of the curves that the hearing records of the several groups offer, and in addition, present them in such form that group differences are directly apparent and recognizable. Such a form of distribution makes unnecessary the use of graphic curves.

In Table IV., p. 34, are given the distributions of the individuals of the three most numerous groups according to age. All the data relating to the smaller groups will be presented in detail in connection with the discussion of their several individual results. Again, making a cursory review of the data in Table IV. the fact is revealed that in case of the Whites, Indians, and Filipinos, the age lines were rather closely drawn. I accepted the record of no individual whose age exceeded 30 years or fell below 16. This was done as in the case of the data relating to the upper threshold of hearing, in order to secure, so far as practicable, homogeneous groups. The average age of the Whites selected was found to be 23 years and 5 months; of Indians, 19 years and 2 months; and of the Filipinos, 21 years and 1 month. For an acuity test I do not think this difference in average age is such as to be very significant.

We shall now proceed to a consideration of the data in detail:

Whites.—Whites, such as those selected for these tests, individuals in the prime of life, men and women who have never experienced any difficulty in hearing, according to these experimental data are able to sense and interpret on the average, a stimulus produced by the action of an air wave, amounting to a pressure difference of 5.5×10^{-9} atmospheres or 7.5×10^{-7} ergs. This indeed is a pressure difference smaller than it is possible to secure in the most rarified *vacua.*[1]

It is rather difficult to compare this value with the figures which have been obtained by other observers, largely because of the different experimental conditions under which the tests have been made. In the first place, I have been unable to find data based on the measures of more than a dozen individuals, and, indeed, since the range of individual differences in hearing acuity is as 100 to 1, within a single group, any discrepancies which exist may very plausibly be accounted for because of the paucity of numbers constituting the groups compared. Again, Wien[2] has shown that the ear's sensitivity for tones is a function of their pitch, and that its sensitivity for different pitched tones varies within rather extreme limits. The vibration number of the tone used is, consequently, no

[1] See Rayleigh, *Phil. Mag.* 38: 300. 1894.
[2] *Pflüger's Arch.* 97: 1. 1903.

doubt, also an important factor in accounting for discrepancies noted.

The vibration frequency of the tone I employed I could not definitely establish. After repeated assays to fix the dominant tone by comparison with other tones of known vibration frequencies, I finally selected 500 double vibrations as being most nearly correct. But, although I think the dominant tone did not vary far from 500, there is no question but that some very pronounced over-tones present were quite effective in favoring acuity. Wien's[4] figures for a tone of approximately 400 D. V. was 1.2×10^{-10} ($E = 8.0 \times 10^{-11}$ ergs) for his own ear, when a telephone instrument furnished the sound. The figure was practically the same with a tuning fork and the Helmholtz's resonators, namely, 8.0×10^{-10} ($E = 3.6 \times 10^{-9}$ ergs).[5] Wien's results, however, make the ear to be almost one hundred times more sensitive than the experimental results of previous observers had led them to believe. For example: Toepler and Boltzmann,[6] who, according to Lord Rayleigh, were the first to make an experimental determination of this question found, with tuning forks, that the value of a sound wave's condensation at the ear, to be just audible, was 6.5×10^{-8}. This figure differs but slightly from Lord Rayleigh's own conclusions from experiments with Wolf's bottle[7] where $\Delta = 4.1 \times 10^{-8}$ for a tone of 2,730 D. V. The same writer found $\Delta = 4.6 \times 10^{-8}$ when a tuning fork[8] of 512 D. V. was employed as the source of sound.

Professor Wead,[9] also employing tuning forks found for a tone of c^2 that $\Delta = 7.1 \times 10^{-9}$ ($E = 1.1 \times 10^{-6}$ ergs) was still audible. P. Ostmann[10] with tuning forks (256 D. V.) places the threshold at $\Delta = 2.1 \times 10^{-8}$ ($E = 8.0 \times 10^{-6}$ ergs). These latter results are pretty much in accord with some recent experiments of Zwaardemaker and Quix,[11] who find that tones from a tuning fork of pitch c^2 in which $\Delta = 1.5 \times 10^{-8}$ ($E = 5.4 \times 10^{-6}$ ergs) might still be heard. More recently still,[12] they secured a somewhat smaller figure $\Delta = 7.1 \times 10^{-9}$ ($E = 1.3 \times 10^{-6}$ ergs). Lord Rayleigh's results from his telephone experiments lead him to think his previous figures placed the sensitivity of the ear too low, since some of his

[4] *Pflüger's Arch.* **97**: 33. 1903.
[5] Dissert. s. 46, 1888; also, *Wied. Annal.* **36**: 849. 1889.
[6] See Lord Rayleigh, "Theory of Sound," II., p. 433.
[7] *Proc. Roy. Soc.* **26**: 248. 1877.
[8] *Phil. Mag.* **38**: 270. 1894.
[9] *Amer. J. of Sci.* **36**: 36. 1883.
[10] *Arch. f. (Anat. u.) Physiol.* 1903, S. 321.
[11] *Arch. f. (Anat. u.) Physiol.* 1902, S. 393.
[12] *Ztschr. f. Psych.* **33**: 401. 1904.

subjects were able to still hear when $\Delta = 1.1 \times 10^{-9}$ ($E = 2.8 \times 10^{-8}$ ergs). The first figure is about the same ($\Delta = 8.88 \times 10^{-9}$) as has more recently been gotten by Webster[13] with his "*phone.*"

It was noted above that Wien's figures are from 40 to 100 times smaller than my own and those of the other investigators. Zwaardemaker and Quix[14] attribute Wien's excessive sensitivity of the ear to the fact that the telephone receiver was held snugly against the ear and that hearing was assisted by molecular bone conduction in addition to the molar sound energy passing over the ossicles.

From the character of my own data it is easy to explain differences in auditory acuity as great as 20 times, such as have been obtained by different observers, where experiments have been limited to a few subjects. Among my white subjects, although not a single individual had ever observed any diminution in his hearing function, the person with the best acuity required about 400 times less energy to just excite an auditory sensation than did the one who heard most poorly. And, indeed, the individual with the keenest ears heard about 90,000 times as well as did the poorest among Filipinos, although in conversing with these Filipinos it was not possible to detect any hearing deficiency. Wien[15] reported two cases of individuals who are still able to hear loud speech but whose hearing is from one to ten million times poorer than normal. Ostmann[16] concluded that a dimunition of hearing of one half or one-third is of slight consequence. The range of efficiency in hearing among normally hearing people is a question which, to my knowledge, has never before been investigated in this way. Ordinarily, it appears unreasonable to believe that in speech the human voice covers such wide latitudes of intensity that a person can speak 300 or indeed 1,000,000 times as loud at one time as at another and yet not be speaking appreciably loud. Our difficulty, perhaps, arises from comparing a hearing test such as the one under consideration, with the ordinary visual acuity tests in which the units are the angles subtended by light rays coming from opposite parts of the letters. These tests obviously are incomparable. But only recently von Kries[17] has shown that the minimum intensity of light necessary to excite the eye amounts to only 1.3 to 2.6×10^{-10} ergs. To see an object, 5.6×10^{-10} ergs is essential, about the same quantity of energy that Wien discovered necessary for sound, and about $\frac{1}{50}$ the

[13] Boltzmann-Festschrift, 1904, p. 874.

[14] *Ztschr. f. Psych.* 38: 408. 1904.

[15] *Pflüger's Arch.* 97: 37. 1903.

[16] *Arch. of Otology,* 34: 207. 1905.

[17] *Ztschr. f. Psychol. u. s. w.* 41: 393. 1907.

quantity necessary to excite a sensation of sound on the average according to my own experimental results. Between the intensity 2.6×10^{-10} ergs and that of ordinary moonlight, the difference is millions, and between the intensity of moonlight and that of sunlight, there is again a difference of at least 100,000. It is such differences with respect to the eye which have their counterpart in the field of hearing. Indeed, extremely great differences in the intensity of tones are not so commonly noticed as one would think. The singing of a thousand voices, though noticeably louder than that of a single singer, certainly does not appear 1,000 times as great. Under certain atmospheric conditions in the quiet country, it is possible to hear, quite distinctly, a human voice at a distance of two miles. If the loudness of the voice when at a distance of 11,000 feet be compared with that when audible only 10 feet from the speaker, some conception may be had of differences of intensity amounting to at least 10,000 to 1 and perhaps 1,000,000 to 1. In the light of such comparisons the figures showing the range of sensitivity of the normal ear are not exceptionally striking.

It will be noted that not only in the case of Whites but in those of the records of all of the groups, the average deviations are extremely large. Such of necessity must be the case, however, when the unit of measurement is extremely small, such as are physical units of sound. Although such fineness of measurement is not essential, it can not well be avoided. Our units are fixed beforehand and with these we are measuring physiological and psychological conditions as they are found among individuals. Part of the large average deviation, indeed, may also be explained by the disproportionately large number of the cases found below the mode in the curve, which arises from the inability which we experience to mark off accurately the normal from the pathological in any functioning. In a way, I sought to eliminate some of the error arising from this source by presenting an average of the mean cases only, as appears in Table XVI. But, even under such restrictions, the average deviation amounts to about one third of the average result in each of the several groups. From this it appears that so far as the hearing function goes, individuals do not distribute themselves so as to conform closely to the laws governing the normal frequency curve.

Indians.—(For a more detailed description of this group, see Chapter II.) The 64 Indians tested for simple auditory acuity, whose records are here presented, are the same whose records formed the basis of the study on the upper threshold of hearing for Indians, as already presented. Included in this group are the records of 14 full-blooded males and 13 mixed bloods, with 4 full-blooded females

and 33 mixed bloods. Five of those tested were over 25 years; 81 per cent. were between the ages of 16 and 20 years. (See Table IV., p. 34.)

It must be recalled that these Indians included under the general caption "Indian" were those only attending the Model Indian School at the Exposition, who, previous to their coming to St. Louis had been in attendance, for some considerable time, at various Indian schools throughout the United States. As has already been pointed out, in habits and culture they are to be distinguished from the Indian of the forest and plain, hence, my reason for grouping together all these Indians from the schools representing a number of different tribes. For the same reason I have chosen to consider separately those tribes representing Indians who came from their natural habitats, and who, therefore, more nearly constitute what might be called representatives of the typical Indian.

For the right ear, the figure representing the condensation of a sound wave which on the average is required to just excite the organ of hearing of the Indians at the Model Indian School, is 7.5×10^{-9} ($E = 14.2 \times 10^{-7}$ ergs) and for the left ear 8.5×10^{-9} ($E = 18.2 \times 10^{-7}$ ergs). The figure for the right ear is 1.34 times larger than that for the corresponding ear of Whites, and for the left ear 1.18 times larger. On account of the relatively large average deviations these differences are not so significant as at first hand one might suppose. Still, the mathematical probability of a difference in favor of Whites is not unimportant. On the basis of the data, the chances are nearly 200 to 1 in favor of the superior auditory sense of Whites for the right ear, and 6 to 1 in case of the left ear. Arguing from Table XVI., where the individual records included in the average are restricted to those lying about the mean, the superiority of the hearing of Whites over Indians is more strikingly brought out, especially as regards the right ear. The average for Whites shows a keenness of hearing which is just about two times that for Indians. In the averages of the left ear, however, the size of the difference between the two groups is lessened, a condition, no doubt, due to the fewness of the individuals comprising both the groups under comparison.

Where the individual records are so widely dispersed as are these, instead of grouping themselves rather closely about the mode, the character of the distribution, as a whole, is really more significant in the way of indicating group differences than the figures representing the averages of the two groups to be compared. A comparison of the hearing of Indians and Whites respectively can easily be made by reference to tables XVII. and XVIII., where the individual

records have been distributed according to relative position. It is clearly apparent that the modes of the distributions of the Indian hearing records—if such a term as "mode" is really applicable to such a form of distribution—fall rather decidedly lower than do those in the curves of Whites. Moreover, it is seen that the general distributions of the hearing records for Whites stand distinctly higher than do those for Indians for both ears, demonstrating that Whites as a whole hear better than do Indians, although many of the Indians, to be sure, possess ears that are more acute than the average acuity for Whites. Of the 64 Indians, however, the ears of 13 only, or about 20 per cent., rank as high as the median record for American or European ears as regards the right ear, and for the left, 24 Indians hear better than the median hearing record for Caucasians, or about 38 per cent. Taken all in all, therefore, the data point rather decidedly toward a superiority of the hearing of Whites over that of Indians; such Indians at any rate as constitute the groups here considered.

The numbers are rather small to indicate reliable sex differences; 27 men and 37 women. But the average acuity of the men, for the right ear, amounted to $\Delta = 7.4 \times 10^{-6}$ ($E = 1.38 \times 10^{-9}$ ergs); of the women for the same ear it was $\Delta = 7.5 \times 10^{-6}$ ($E = 1.42 \times 10^{-9}$ ergs). For the left ear, the figures for men and women respectively were $\Delta = 8.5 \times 10^{-6}$ ($E = 1.83 \times 10^{-9}$ ergs) and $\Delta = 8.4 \times 10^{-6}$ ($E = 1.78 \times 10^{-9}$ ergs). If we should argue from this group alone, therefore, sex differences in hearing, among Indians, do not exist.

The Cocopa (or Seri) Indians.—(For a more detailed description of these people, turn to Chapter II., page 6.) Of the Cocopa Indians I was able to secure ten hearing records, all of males. Owing to the fact that the number is so small, I shall present the data relating to the hearing of the various individuals in detail:

AUDITORY ACUITY

Name	Age	Right Ear ($\Delta = x \times 10^{-6}$)	Right Ear ($E = x \times 10^{-9}$ ergs)	Left Ear ($\Delta = x \times 10^{-6}$)	Left Ear ($E = x \times 10^{-9}$ ergs)
Shik	14	6.2	9.5	8.1	17.0
El Puck	15	6.2	9.5	6.2	9.5
Hi	8	4.0	4.0	5.0	6.3
Jack	17	6.2	9.5	5.0	6.3
Mert	14	11.9	35.0	(64.8)	(1060.0)
John Roy	18	6.2	9.5	2.5	1.6
Joe	20	14.1	49.0	18.1	80.0
Jerry	42	3.3	2.8	6.2	9.5
Pablo	55	(64.8)	(1060.0)	21.1	110.0
Tom	70	(214.9)	(8260.0)	(214.9)	(8260.0)
Average		7.28×10^{-6}	16.1×10^{-9}	9.02×10^{-6}	20.2×10^{-9}

It will be observed that the individual differences are considerable, which makes the average of relatively little value as a figure to represent the hearing efficiency of the group. Of the ten hearing records made, I rejected, as being palpably pathological, two for the right ear and two for the left; those which have been enclosed in parentheses. Even with the elimination of these records, not only on the average but in almost every individual case the records for the Cocopas are below the median record of Whites for both the right and the left ears. The single exceptions to this statement are that of Jerry, whose record for the right ear is slightly superior to the median record for the Whites, and that of John Roy, who hears slightly better with his left ear than the median of Whites. Some of the auditory deficiency manifested by these people is undoubtedly mental, but it is improbable that all can be attributed to this factor, inasmuch as some of the individuals tested were fairly bright young men and, moreover, took a decided interest in the hearing test. I questioned some of the men as to their apparent hearing deficiency, with the result that the difficulty was attributed to ear afflictions, from which it appeared almost every individual had suffered in time past. These were said to be due to exposure to storms and inclement weather. But why the Cocopa Indian should particularly be a victim to the inclemency of the weather, it is hard to imagine, inasmuch as he dwells in a tropical land, where the climate has a tendency to be arid. And besides, the Cocopas' ears are usually very completely protected by the dense mat of tarred hair which is allowed to grow long and hang loosely about the head, thus covering the ears almost completely.

The number of individuals measured was too few to speak definitively, but it seems fairly safe to assume that Cocopas do not have auditory acuity which is equal to that of Whites. It is almost certain that it is not superior.

The Vancouvers (*Nutken and Kwaguitl*) *Indians.*—(For a description of these people, see Chapter II., page 8.) I was able to secure records of the auditory acuity of all seven of these Indians, from the southern portion of Alaska, who were present at the Exposition. I shall present the data relating to this group in detail, as shown in the accompanying table.

On the average, it is seen that these Indians have an acuity of hearing only about one half as great as do the whites (see Table XV., p. 90). Considering the large amount of variation among the records, the averages for right and left ears respectively do not differ to any significant extent. The records of the two women show an acuity strikingly poor, though the records are probably not repre-

AUDITORY ACUITY

Name	Age	Tribe	Right Ear		Left Ear	
			$\Delta = \times 10^{-9}$	$E = \times 10^{-7}$ ergs	$\Delta = \times 10^{-9}$	$E = \times 10^{-7}$ ergs
Bob	40	Kwaguitl	3.3	2.8	5.0	6.3
Jasper	27	Nutken	14.1	49.0	13.1	80.0
Jack Curley	21	"	6.2	9.5	4.0	4.0
Charley Newell	28	Kwaguitl	8.1	17.0	3.3	2.8
Ellen	35	Nutken	18.1	80.0	15.7	64.0
Anna	30	"	10.3	28.0	14.1	49.0
Atleo	64	"	(29.9)	(2300.0)	(29.9)	(2300.0)
Average			10.01	31.06	10.03	34.3

sentative of the Vancouver Indian women as a whole. Atleo, an old man, made a poorer record than the women, as did also Jasper, but Jasper had experienced a hearing difficulty at one time, although when the test was made he did not believe his hearing in any way defective.

One of the seven had an acuity equal to that of the median of Whites with the right ear, three with the left, but, on the whole, the hearing records of the Kwaguitl and Nutken Indians are low, making it plausible to believe that the Alaskan Indians as a class possess an auditory sensitivity decidedly less acute than do Americans and Europeans.

Patagonian Indians—The Tehuelche.—(For a description of these people see Chapter II., p. 10.) I was able to make tests on four of the Indians of this tribe only, all being men. The data relating to their auditory acuity, in detail, follow:

AUDITORY ACUITY

Name	Age	Right Ear		Left Ear	
		($\Delta = \times 10^{-9}$)	($E = \times 10^{-7}$ ergs)	($\Delta = \times 10^{-9}$)	($E = \times 10^{-7}$)
Cosimero	24	7.1	13.0	7.1	13.0
Canejo	35	5.0	6.3	29.9	230.0
Senchel	55	(127.2)	(4300.0)	(127.2)	(4300.0)
Boni Farci	18	34.9	160.0	14.1	49.0
Average		12.3×10^{-9}	59.7×10^{-7} ergs	17.01×10^{-9}	97.3×10^{-7} ergs

For neither ear, is there a single record of the hearing of these Indians which is as good as the median record for Whites. On the average, their auditory acuity is less than one-half as good as that of Whites for each ear. Moreover, these were not old men nor were they in any respect prematurely aged. On the contrary, they were sturdy, vigorous, and in good health. Indeed, so far as I was able to learn, there was no apparent physical reason why their hearing

should not be good. We may not assume, however, that a group as small as this is representative of the Patagonian natives.

Resumé of the Hearing of Indians.—If, now, we group the native Indians together and consider them as a single group, we have altogether twenty records. (Table XVII.) It is thus seen that only two of the twenty native Indians have auditory acuity records equal to the median for the right ear of Whites, and three for the left ear. While even yet the whole number measured is not large, it certainly is sufficiently great to justify the rather positive inference that, on the whole, Indians hear less well than do Whites. Furthermore, if we compare this group of native Indians with those who have been in attendance at the U. S. Government Schools, it will be noted as striking that the more intelligent Indians—those who have been subjected to the influences of civilization—have a better auditory acuity than do those who have been closest to nature and a natural life. So far as our American Indians of the plains are concerned, therefore, it can not be averred that their senses deteriorate with increased contact with civilization.

Filipinos.—(See Chapter II., page 6, for a description of these people.) Of the Filipinos, I measured the hearing of 137 individuals. As will be seen by reference to Table IV., the Filipinos were all men in the prime of life, in fact, young men in their teens or just beyond twenty. A more favorable group of individuals for testing it would be difficult to find, and especially is this true when we remember that for the most part they were also rather decidedly above the average of native Filipinos in intelligence and social culture. The group had been selected somewhat on the basis of hearing before reaching the United States. In choosing the men for army service those men had been rejected whose auditory acuity was discovered to be too low. Just what was the nature of the auditory test I was unable to learn, but from the information which I could glean from the men and officers in charge, and from requirements in other particulars, made of those enlisted in the Filipino service, I would judge that nothing more was required in the way of hearing acuity than ability to understand military directions spoken in an ordinary tone of voice.

The relative position occupied by the Filipinos as regards their auditory acuity may be seen by reference to the data in tables XV., XVI., XVII. and XVIII. (pages 90–92). In terms of the average result of the group, for the right ear, the condensation of a sound wave (Δ) must equal 24.2×10^{-9} ($E = 160.0 \times 10^{-7}$ ergs) and for the left ear 26.6×10^{-9} ($E = 171.0 \times 10^{-7}$ ergs) to excite an auditory sensation such as is required to interpret the stimulus in the

hearing test herein employed. It may be noticed that the figures for Whites are 5.6×10^{-9} ($E = 7.7 \times 10^{-7}$ ergs) and 7.2×10^{-9} ($E = 12.0 \times 10^{-7}$ ergs) for the right and left ears respectively. These are rather extraordinary figures, in that they indicate that on the average Filipinos possess a sense of hearing which is only about one twentieth as keen as Whites, taking as a basis of comparison the acuity of the right ear of the two groups. This means that Filipinos on the average require 21 times as much energy to excite an auditory sensation as do Whites. For the left ear the sonorous energy required is about 14 to 1 in favor of the Whites. The difference between the two groups is so marked that there does not appear the slightest chance of its obliteration, however large the groups of Filipinos and Whites respectively might be made. To be sure, the average deviations for Filipinos are large; but no larger, proportionately, than are the corresponding deviations for Whites.

Applying statistical methods to the data, for the two groups, to ascertain the relative mathematical certainty of a difference in their hearing, it is found that the chances in favor of a difference between the groups are practically infinite. The chances are 300 to 1 that the difference in condensation of a sound wave required to excite hearing, between the two peoples is at the least 15.00×10^{-9}, or 300 to 1 that the hearing acuity of Filipinos is only one ninth that of the Whites for both ears. *Exactly* the same differences appear if we select only the median cases—the 50 per cent. of the cases distributed equally about the median—as will appear by reference to Table XVI. (p. 90). Referring now to tables XVII. and XVIII., it is seen that, for the right ear, nine Filipino hearing records only, and for the left ear but six of a total of 137, are as high as the median record of Whites.

When the hearing was being tested at the Exposition, both Professor Woodworth and I noticed that the Filipino peoples were doing very poorly indeed. At first, there was a disposition to attribute it to a defect in the working of the instrument. But this was found to be untrue, since a comparison of my own hearing record, which always immediately followed that of each Filipino tested, showed the testing device to be working normally.

I am at a loss to account for this remarkable difference between the auditory acuity of the Filipinos and Whites. One point of interest has already been referred to in connection with the discussion of the upper limit of hearing of these people. It was remarked in that connection that some of the Americans who had resided in the islands for two or three years had observed that their own hearing was very poor while in the Philippines, a fact which they be-

lieved to be attributable to over-dosing with quinine, a drug which they found it necessary to use freely to ward off tropical fevers. But, as was then stated, Filipinos are immune to attacks of these febrile diseases. They use no quinine or other drug with like property, so the explanation of auditory inferiority which takes into account the use of quinine, is unsatisfactory so far as it relates to the natives. Were the relative inferiority confined to this one hearing test alone it might be interpreted as at least in part due to the Filipinos' inability to react to the test from one cause or another. But a like unfavorable difference, it will be recalled, was found to obtain with reference to their upper limit of hearing. The inferiority probably extends to all phases of hearing.

In order to determine to what extent the records from this test would correlate with those for the upper threshold of hearing, I worked out the Pearson coefficient of correlation[18] for all the Filipino records, employing both methods—for relative position and for average difference. By the first method, the coefficient of correlation between auditory acuity and the upper limit of hearing of Filipinos was + 0.2907. By the second method, the coefficient of correlation between the two amounted to + 0.5408. The amount of correlation is certainly fairly large. And, taking into consideration an instrumental error amounting to between 5 and 10 per cent. in each series, the degree of correspondence is about as great as might be looked for where the measures are of quantities that are as variable in nature as are those of any sensory test.

Looking at the distribution of the records of individuals in the two tests respectively we discover that of the 25 individuals who ranked highest in auditory acuity, 18 are among the 25 highest in the upper limit test, and of the 25 individuals who ranked lowest in auditory acuity—*i. e.*, did most poorly—21 are also among the 25 poorest in the test for the upper threshold of audibility. The character of the coefficient of correlation together with the figures showing the correspondence in the cases of the records at the extremes, although they indicate that some definite correlation exists between hearing acuity and the limit of hearing, do not show a point for point correspondence such as to justify one test for both functions in a purely functional hearing test. The results furnish evidence, it seems to me, in support of the theory that in its ultimate analysis, pitch discernment is closely related to the factor of intensity.

The relation that exists between auditory acuity and intelligence

[18] $r = \Sigma xy / n\sigma_1\sigma_2$, in which r is the required coefficient; x and y the deviations of an individual from the averages of the two series of measurements; n the number of individuals; σ_1 and σ_2 the standard deviations of the two series of measurements.

was likewise investigated to a certain extent. In connection with other tests and measures, we had the people whom we measured at the Exposition perform certain intelligence tests, which were more or less simple in character. Among the intelligence tests was a simple "form test" which we believed, from observation, to correlate roughly with intellectual ability. The test consisted in selecting certain blocks, cut into geometrical forms, which were arranged in random order, and placing them into holes of corresponding shapes which had been cut into a board. A record was made (1) of the time required to perform the operation as well as (2) of the accuracy with which it was done. Taking the time required to perform this test by Filipinos and their auditory acuity, the Pearson coefficient of correlation was + 0.238. While, therefore, the correlation between intellectual ability, as measured by this intelligence test, and auditory acuity is not very considerable, it does show that intellectual ability is a factor that must be reckoned with in sensory measures, even though the tests be as simple in character as were those of auditory acuity, and especially is this true in the case of tests on primitive peoples.

I had an opportunity to test the factor of intelligence as regards its relation to auditory acuity a little farther, in the case of the Filipinos. Among other Filipinos tested for hearing were fourteen students, who were in attendance at various American universities and colleges. I separated the hearing records of these Filipinos from the others in order to compare them with those of Filipinos of the more humble walks of life. These student records for the hearing of the right and left ears, respectively, I will present in full:

FILIPINO STUDENTS—AUDITORY ACUITY—INDIVIDUAL RECORDS

	Right Ear		Left Ear	
	$A = \times 10^{-9}$	$E = \times 10^{-9}$ ergs	$A = \times 10^{-9}$	$E = \times 10^{-9}$ ergs
1	2.5	1.6	1.9	0.9
2	2.8	2.0	2.1	1.1
3	3.0	2.3	3.3	2.8
4	2.5	1.6	3.3	2.8
5	3.0	2.3	3.3	2.8
6	3.3	2.8	4.0	4.0
7	3.3	2.8	4.0	4.0
8	3.3	2.8	4.5	5.0
9	3.6	3.3	4.5	5.0
10	3.6	3.3	4.5	5.0
11	4.5	5.0	4.5	5.0
12	4.5	5.0	6.2	9.5
13	15.7	64.0	15.7	64.0
14	15.7	64.0	36.5	230.0
Average.	5.0	11.6	6.40	31.5

Of these records of Filipino students, it will be seen that all except the last two are above the median hearing record of Whites, in case of both the right and the left ears. But it has been questioned whether, after all, this difference in hearing between the students and the common native Filipinos is really a matter of intelligence at all but rather due to the fact that these individuals had been longer in the United States and hence had become somewhat more acclimated than had the soldiery, who came to St. Louis directly from the islands. It is difficult to conceive, though, how a climate so different from that in their natural habitat, in which they and their forefathers had lived for centuries, could be effective in bettering a sensory quality. Indeed, the argument would sound more plausible were we to reason conversely that their hearing become poorer in the United States because of their longer sojourn here.

Ainu.—(For a more complete description of these people, see Chapter II.) The composition of the Ainu group was not the most favorable for an auditory acuity test. In addition to the too great variation in ages among the peoples, it appears that to some extent the different individuals of the group were interrelated. In testing a related group such as this, consequently, there is some possibility that what is really being measured is a family characteristic rather than a racial trait. I shall present the records, however, as I secured them:

AINU—AUDITORY ACUITY

Name	Age	Right Ear		Left Ear	
		$\Delta = \times 10^{-9}$	$E = \times 10^{-7}$ ergs	$\Delta = \times 10^{-9}$	$E = \times 10^{-7}$ ergs
Yazo Osawa	23	5.5	7.5	8.1	17.0
Kutorge Hiramura	38	21.1	110.0	25.0	160.0
Goro Bete	28	4.0	4.0	6.2	9.5
Sangea Hiramura	56	4.5	5.0	11.9	35.0
Kin Hiramura (Daughter of Sangea)	6	25.0	160.0	11.9	35.0
Shrutatek Hiramura (Wife of Kutorge)	33	11.9	35.0	18.1	80.0
Ume Osawa (Wife of Yazo)	19	36.5	330.0	11.9	35.0
Santukuno Hiramura	53	36.5	330.0	43.4	450.0
Average		18.12	122.7	17.06	102.7

In making up the averages for this group, I included the records of all the individuals examined, in spite of the fact that they presented wide variations. In case of a doubtful record in making up the averages of larger groups, such as the Whites or the Filipinos, I observed the rule laid down by Professor Cattell of rejecting the record of any individual if its divergence from the average exceeded three times the average deviation. Such a record is more likely to

be an instrumental error or to be a case of pathological functioning than a question of simple deviation from the average. Such a procedure in the case of the records of the Ainus, however, would be difficult to follow.

Of the eight records of hearing for the right ear, five were very poor and only three fair in comparison with those of Whites, while for the left ear, seven of the eight are relatively poor, though for this ear the average shows slightly higher than that of the right. None of the Ainu people, in case of either ear, stand as high as the median records for Whites, for corresponding ears. While it is not permissible to become dogmatic from so small a sampling, it seems probable enough that the average of a large group of Ainu people would show about the same relative inferiority with respect to auditory acuity as was discovered among the few examined. At the time of making the examinations, and again some months later, I inquired carefully of each person whether he or she had ever observed that his hearing was defective, but the replies were invariably in the negative. There is no way in which the question can be investigated other than by the method of observation and selection, but I am convinced that the inferiority of the Ainu in respect to this sense is due in no small part to their sluggishness in reacting to impressions. So sluggish and unresponsive are they, that a stimulus of more than ordinary intensity is required to arouse them, and it seems not unnatural that weak auditory stimuli should fail to break over the threshold of consciousness. Confirmatory of this opinion is the fact that of the eight individuals tested, the three who were the most intelligent and alert of the group were likewise the three who possessed the best records of hearing acuity.

No effort was made to differentiate the sexes in the tests, though it will be seen from the data that the average acuity of the women is considerably less than that of the men. The record of Kin was high also, and perhaps should have been omitted in making up the average, but she seemed to understand the procedure and to react as intelligently to the questions put to her as the average of her people, and for this reason her record was included with the others.

Pigmies.—(For a description of these people see Chapter II., page 9.) It would, perhaps, be better to consider this group as one of native African Negroes, rather than of a particularly primitive or aboriginal race. Some of the number, at least, were not Pigmy at all: they belonged to a type of large red negro found in the central Congo district. Yet even as regards Negroes who have been little influenced by the habits and arts of civilization, they will give

instructive information. I shall give the data relative to their ages and tribal connections as it was given us together with the hearing records which I was able to make, in the following table:

PIGMIES—AUDITORY ACUITY

Name	Age	Tribe	Right Ear		Left Ear	
			$\Delta - \times 10^{-9}$	$E - \times 10^{-7}$ ergs	$\Delta - \times 10^{-9}$	$E - \times 10^{-7}$ ergs
Shamba............	30	Batwa	6.2	9.5	6.2	9.5
Malinga...	16	"	11.9	35.0	9.1	21.0
Bushaba	13	"	18.1	80.0	7.1	13.0
Latuna	15	Batsuba	9.1	21.0	9.1	21.0
Lumme	17	"	6.2	9.5	6.2	9.5
Average...........			10.31	31.0	7.54	14.8
A. D................			3.55	20.8	1.24	7.6

In contrast with the records of the Ainu just considered, it is seen that the Pigmies present a rather homogeneous group so far as auditory acuity is concerned. For both ears the average deviations are small. This probably is due, at least in part, to the fact that the individuals were about of an age, and differed little temperamentally from one another. It will be remembered that for the upper threshold of hearing the Pigmy records were all high, and if the same relative distribution were to follow, were the number increased indefinitely, Pigmies would possess an upper threshold for hearing superior to that of any other race, not being inferior to even Whites in this respect. An equal degree of superiority was not attained by Pigmies in auditory acuity, although for the left ear (see Table XV.) the average acuity of Pigmies is slightly higher than that of the same ear for Indians who next approach Whites in keenness of hearing; the record for the right ear falls below that of both Whites and Indians. Little significance perhaps may be attached to an average measure, where the numbers measured are so few, but the character of the distribution of the group seems to indicate a decided inferiority for the hearing of the Pigmies as compared with those of both Whites and Indians. The curve of their hearing falls perceptibly lower, the average being relatively higher owing possibly to the fact that none of the Pigmies possessed anything in the way of an organic hearing defect, which might tend to lower the standing of the group. An explanation of the differences found between the comparative records of Whites and Pigmies in the upper threshold of hearing and for simple acuity respectively might be given on an intellectual basis. In the test for the upper

threshold of hearing, the stimuli are of longer duration. Moreover, they require no interpretation, and consequently the feeling of hearing the sound, which really has only a subthreshold value, may be more easily accomplished, than the actual interpretation, which the counting of the stimuli, implied in the simple acuity test, necessitates. I put this forth as suggestive only.

CHAPTER XI

SUMMARY AND CONCLUSION

IT is very difficult to compare the foregoing results with those of Myers in the same field, by reason of the differences in the method employed in collecting data. In the classic work of Myers, on Papuan hearing, several different devices for testing the hearing of the primitives were employed.[1] And to such an extent were these different measures therefore confused that it was necessary for Myers to report all the data he collected in terms of a personal fraction in which the hearing of one of the members who made up the expedition was the denominator, while that of the subject constituted the numerator. Of the 35 Islanders who were examined for auditory acuity by Myers, the hearing of seventeen only was reported and of these twelve were children, five only being adults. Of the children five could hear as far as Myers; seven were clearly inferior; and of the adults examined, all possessed a very low acuity. Although consequently I can speak only in general terms, Myers's conclusions do not appear to differ essentially from my own in this, that they point out clearly the obvious superiority of Whites over primitive races in the keenness of their hearing sense.

With my smaller groups, as has been repeatedly stated, the number examined is insufficient to do more than indicate a general tendency of the group within the region of a large probable error. Especially is this true of such peoples as the Vancouvers, the Pigmies, and the Cocopas, where it is difficult to predict with any degree of probability the character that the hearing curve of the peoples as a whole might assume, inasmuch as the records are so scattered—some being fairly high; others extremely poor. But in the case of such groups as the Indians, Filipinos and Whites, the number of measurements is sufficient to give at least the general character of a complete distribution of the race as a whole.

Taking the results of all the groups examined for what they are worth their standings respectively are as follows, as regards the acuity of the right ear:

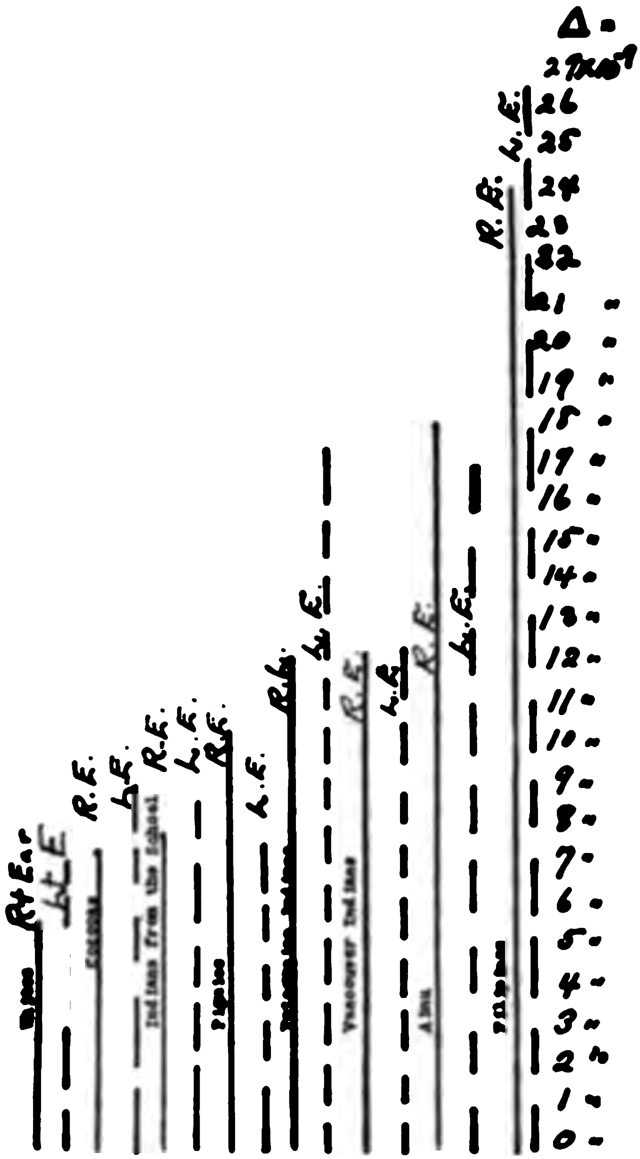
Whites; Cocopas; Indians from the School; Pigmies; Patagonian Indians; Vancouver Indians; Ainu, and lastly, Filipinos.

For the left ear, the order is slightly changed, Whites and

[1] See Report of the Cambridge Anthropological Expedition to Torres Straits, Vol. II.

Filipinos, however, still retaining the positions at the two extremes; the order from the most acute people to the least acute being:

Whites; Pigmies; Indians from the School; Cocopas, Vancouver Indians; Ainu; Patagonians and Filipinos.



It will be observed that the relative positions of the three most numerous groups, namely Whites, Indians from the School, and

Filipinos remain unchanged. Indeed, they retain in respect to each other about the same relative position for both the right and left ears, and also, when the basis of comparison is that of absolute units of hearing, instead of relative position. To summarize the various comparisons which have been made in connection with the data relating to the several groups, we may show the following ratios indicating the relative keenness of the hearing sense of each group as compared with that of Whites:

		Right Ear		Left Ear
Whites—Cocopas	Ratio	7 to 5	Ratio	9 to 7
Whites—Indians (School)	"	9 to 5	"	8.5 to 7
Whites—Pigmies	"	10.5 to 5	"	7.5 to 7
Whites—Patagonians	"	12 to 5	"	17.5 to 7
Whites—Vancouver Indians	"	10 to 5	"	10 to 7
Whites—Ainus	"	18 to 5	"	17 to 7
Whites—Filipinos	"	24 to 5	"	26.5 to 7

Preyer, Fechner,[1] Bezold and others have observed that in hearing tests, the left ear in general is more acute than the right. Miss Nelson,[2] on the contrary, found that in both men and women the right ear was the better. The left ear, it will be remembered, was found to be superior with respect to the tests for the upper threshold of hearing. In case of the ears of each of the larger groups, my own experiments in general confirm the observations of Miss Nelson as opposed to those of Fechner and Bezold. The acuity of the left ear not only of the three larger groups but in three of the five smaller ones, is clearly inferior to the right, the Pigmies and Ainus alone being exceptions. When making the measurements of the upper threshold, it will be recalled that it was stated that almost invariably the right ear was first tested. In consequence, I believed the superior upper limit of the left ear to be due to the effect of practise in hearing shrill tones. But this explanation will not apply to the case of the acuity test. Instead of testing invariably one particular ear first, the process was alternated—the right and left ears alternately being first tested in successive subjects. Practise effects could not, therefore, have been operative in causing the average for acuity of one ear to be higher than the other. It is, indeed, more probable that the causal factor is organic rather than psychological.

The one fact standing out most prominently as a result of these measurements is the clearly evident superiority of Whites over all other races, both in the keenness and in the range of the hearing sense. The evidence is so clear and striking as to silence effectually the contention that the hearing function, inasmuch as it is of rela-

[1] *Poggendorf's Annal.* (4th series) 3: 500.

[2] *Psych. Rev.* (suppl.) 13: 280. 1906.

tively less utility in the pursuits attending modern social conditions than those surrounding the life of the savage, has deteriorated and is degenerating. On the contrary, they are more nearly in keeping with the advanced positions taken by modern dynamic psychology, to the effect that not only the intellectual but sensory possibilities are to be stated in terms of the variety of motor response of which the individual is capable. Other things being equal those individuals or races possessing the greatest complexity and variety of reactions to elements in their respective environments likewise will be gifted with keener and more acute sensory mechanisms.

If all discrimination of data coming to the senses must finally be stated in motor terms, as most psychologists would have us think, then those peoples whose social activities call for the greatest complexity of response will, of necessity, possess keener senses along those lines in which the social media call for closer discrimination. This motor aspect of a sensory function also serves, to a certain extent, to explain a rather startling auditory inferiority on the part of some of the natives of tropical lands. In these regions of warmth, where lack of thrift and indolence are fostered by nature's bounty, in its luxuriance and plenty in the way of food, in its relative immunity from exigencies calling for protection and shelter, adaptive activities are found at their lowest ebb. Contrast these conditions with those of higher latitudes, in which the individual is in constant strife to keep himself in harmony with his surroundings. And the ear plays no insignificant rôle in this endless round of readjustment. Roughly, and in general, the data on hearing were found to correlate with motor versatility as regards the different races.

Then again the more involved a test, the more probable is it that differences in the degree of intelligence of the subjects tested will be effective in modifying in an unfavorable direction the performance of the less gifted group. It has already been indicated that the test for auditory acuity which I employed was more than a simple sensory test, inasmuch as it required an interpretation of the stimuli presented to the ear, and for this reason it was believed that some of the differences between the acuity of the several peoples tested might be attributable to the obvious fact that striking differences in mental alertness obtained among the different races. But to what extent the mental factor was responsible for the degree of auditory inferiority in such a race as the Filipinos, it is impossible to tell with any degree of certainty from the data at hand.

Only two factors have been indicated to account for differences in auditory acuity found among primitive races, and between primitive races and Whites. That there are many others, some perhaps